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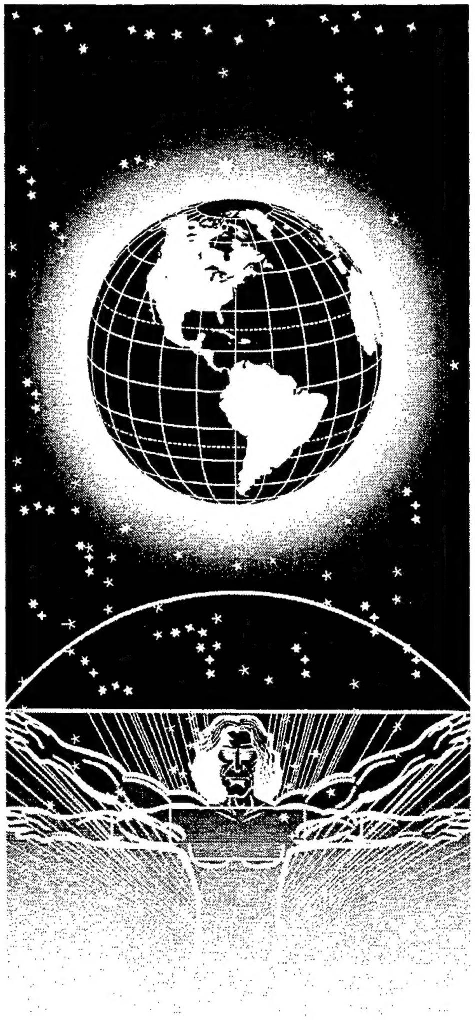

UNITED STATES AIR FORCE RESEARCH LABORATORY

THE EFFECTS OF TASK LOAD AND SHARED DISPLAYS ON TEAM SITUATION AWARENESS

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FOR THE COMMANDER

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In this study, we empirically tested the effects of abstracted shared displays and varying workload levels on the formation of team situation awareness (SA). We hypothesized that the use of abstracted shared displays might help to build team SA without imposing the extra workload. Secondly, we wished to further explore the issues associated with workload level and its affect on both team interaction and on the use of the shared displays in the development of team strategies for performing the task. Results supported the use of shared displays for enhancing team performance. However, the way in which people use shared displays was actually quite complex and related to both task strategies used and workload level. We found a greater increase in both penalty and reward points as the task got more difficult. Team interaction also declined as workload increased. The workload level also effected team performance with the display types. Under low workload levels, no performance enhancements or problems were found associated with either shared display. In the high and moderate workload conditions, the penalty points were lowest with the abstracted display and highest with the full shared display. The use of an abstracted display also seems to decrease the need for team interaction. Overall, team SA and performance in team tasks can be greatly enhanced by the development of shared displays, particularly under high workload levels, that are based on the shared information requirements of team members.

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PREFACE

This report was prepared for Logicon Technical Services Inc. (LTSI), Dayton Ohio, Mr. Robert Stewart, Technical Manager, under Contract Number F41624-94-D-6000, Delivery Order 0007. The work was conducted under the auspices of Mr. Gil Kuperman, Air Force Research Laboratory's Human Effectiveness Directorate, under the direction of the Crew System Interface Division, Information Analysis and Exploitation Branch (AFRL/HECA), Wright-Patterson Air Force Base. The authors wish to express our appreciation to both Mr. Stewart and Mr. Kuperman for their very helpful advice and support in the pursuit of this research. The authors also wish to acknowledge their appreciation to Dr. David Kaber, Mississippi State University, for use of the Multitask simulation and Mr. Mark Bolstad for his many hours of support in software development.

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INTRODUCTION

In military operations, tasks will often need to be accomplished through the joint efforts of several individuals. This may include multiple individuals involved in a common effort or in a coordinated activity (such as a joint strike mission). The critical role of teamwork in accomplishing mission-oriented tasks and goals in today's military is unquestionable (Salas, Dickenson, Converse, & Tannenbaum, 1992). Today, mission success demands the coordinated effort of those individuals who have become specialists, as each one of them only has a piece of the puzzle. Only by communicating and coordinating their efforts can the team be successful in a timely fashion. The tremendous volume and complexity of data that the team must encounter and process to construct an accurate tactical picture is overwhelming. This process becomes even more overwhelming with the increased use of distributed interactive networks of teams with members who have a variety of duties and training. Collaborative decision making may be required for effective planning operations, for sharing updates on situational changes (e.g. enemy activities), or for creating effective responses to such changes, and a wide variety of problem solving tasks. Effectively coordinating the activities and decision making of these multiple personnel remains a challenge, however.

This research is directed towards developing effective tools and techniques for assisting individuals in achieving a high level of shared situation awareness (SA) when involved in collaborative decision making tasks such as those to be found in future military operations. This effort will be focused around the problem of providing shared situation awareness. Teams of individuals can be defined in terms of common goals, interdependence of task, and specific roles towards meeting the shared goal (Salas, et al., 1992). In order to perform their tasks, each member of the team (which may be a standing team or may be formed ad hoc for solving some problem) needs to have a certain level of SA. Examining situation awareness as it exists within teams and between teams that are involved in achieving a common goal lends an important perspective for the determination of system designs that support the complex inter-related activities of these teams. Team SA has been defined as "the degree to which every team member possess the SA required for his or her responsibilities" (Endsley, 1995). The degree to which team members possess a shared understanding of the situation with regard to their shared SA requirements is extremely important for developing effective team performance.

Developing shared SA within a team and between teams can be extremely challenging, especially where those teams are distributed in terms of space, time, or physical barriers. This process has been described in a model of team SA as coming about as a function of four components (Endsley & Jones, 1997):

(1) Shared SA Requirements - the degree to which the team members know which information needs to be shared, including their higher level assessments and projections (which are usually not otherwise available to fellow team members), and information on team members' task status and current capabilities.
(2) Shared SA Devices - the devices available for sharing this information, which can include direct communication (both verbal and nonverbal), shared displays, or a shared virtual environment. As nonverbal communications and a shared environment are usually not available in

distributed teams, this places far more emphasis on verbal communication and technologies for creating shared information displays.

(3) Shared SA Mechanisms - the degree to which team members possess mechanisms, such as shared mental models, which support their ability to interpret information in the same way and make accurate projections regarding each other's actions. The possession of shared mental models can greatly facilitate communication and coordination in team settings.

(4) Shared SA Processes - the degree to which team members engage in effective processes for sharing SA information which may include a group norm of questioning assumptions, checking each other for conflicting information or perceptions, setting up coordination and prioritization of tasks, and establishing contingency planning among others.

Recent research has been conducted to explore this model of team SA. Bolstad and Endsley (1998) examined the use of shared mental models and shared displays (components 2 and 3 of the team SA model) as a means of enhancing team situation awareness. The study demonstrated that when members of a team are dependent on each other for successful performance, the presence of a shared mental model helped to improve overall team performance as expected. The mechanism whereby the shared displays aided performance was not direct as expected. Teams actually performed worse with a shared display; however, a residual effect was seen in later trials. After the shared displays were removed, the teams outperformed both their prior performance and other teams that received the non-shared display condition followed by the shared display condition. While the presence of shared displays slowed team performance in this task, most likely due to extra attention demands, they also provided for the development of shared mental models that greatly enhanced performance even after the shared displays were removed. The combination of no shared displays and no mental model was highly detrimental to performance. Teams who experienced this condition first were unable to ever develop very good performance.

In the present study, we sought to expand on the previous research by examining the use of abstracted shared displays. In the previous research, the shared display condition provided each team member with a complete replicate of the other team member's display. This may not be the best way to provide a shared display of information to team members, however. An abstracted shared display instead provides only the critical information from the other team member's display, based on an analysis of shared information requirements (Endsley & Jones, 1997). It is hypothesized that the use of abstracted shared displays might help to build team SA without imposing the extra workload observed with the use of the full shared displays.

Secondly, we wished to further explore the issues associated with workload level and its affect on both team interaction and on the use of the shared displays in the development of team strategies for performing the task. In addition, the Theater Defense team task that was used for the study was enhanced to create a more complex task. The Air Commander was given two different missiles types, each more effective for different types of aircraft in the simulation. Three AWACS-like (Airborne Warning and Control System) aircraft were added to the simulation so that the reliability of the sensors varied over time, depending on the AWACS position. This created a more complex task and furthered the degree of interaction required by the two team members.

METHOD

Participants

Thirty-eight participants served as paid subjects for this research. These participants were recruited from a large Southern university. Two participants (one team) were dropped from the analysis due to their low overall performance (less than three standard deviations below the mean on performance measures). The remaining 36 participants were tested in pairs for a total of 18 teams. The participants (mean age = 23.19 years; range 18-43 years) comprised 21 men and 15 women with an average of 15.31 years of formal education. All participants indicated they had normal or better vision. The participants had an average of 6.93 years of computer experience and were familiar with the general operation of a personnel computer.

Design

Two factors served as independent variables in the study: Workload and Shared Display Type.

(1) Workload Level: Three workload levels (3, 6, and 9) were determined based on the maximum number of aircraft on the display at any one time. These loads were selected as a "low," "medium," and "high" workload level, based on previous research. Workload was a within team manipulation.

(2) Shared Display Types: Non-Shared Displays (verbal interaction only) which served as a control condition, Full Shared Displays, and Abstracted Shared Displays were examined as the three conditions of this independent variable. Shared Display Type was a between team manipulation.

Six teams completed the study in each of the three Shared Display conditions, as shown in Table 1. The order of presentation of workload level was counter-balanced across teams. All teams completed three 6-minute trials at each workload level, for a total of nine trials per team.

Table 1. Experimental Design

Workload Level Order	No Shared Display	Full Shared Display	Abstracted Shared Display
3, 6, 9	Team 1	Team 2	Team 3
3, 9, 6	Team 4	Team 5	Team 6
6, 3, 9	Team 7	Team 8	Team 9
6, 9, 3	Team 10	Team 11	Team 12
9, 3, 6	Team 13	Team 14	Team 15
9, 6, 3	Team 16	Team 17	Team 18

The effects of the independent variables on the performance of the two team members in the Theatre Defense task were examined as dependent variables. The processing outcome for each aircraft (destroyed, passed through, or collided), time to process a target, and reward and penalty points were recorded for the Air Commander. The time to make an identification, correctness of

identification, and the use of the Air Commander's prioritization order were recorded for the Intelligence Officer. Verbal communications were also recorded between team members, including both inquiries and information provision to the other team member.

Procedure

Teams were tested one at a time. Team members were given a handout describing their task within the Theatre Defense team task. See Appendix A for the Intelligence Officer's job description for Non-Shared and Full Shared Display conditions and Appendix B for the Abstracted Shared Display condition. See Appendix C for the Air Commander's job description for Non-Shared and Full Shared Display conditions and Appendix D for the Abstracted Shared Display condition. In the Abstract Shared Display condition, information regarding the additional abstracted displays were included in the instructions.

Teams in the Non-Shared Display condition were not given any information regarding the other team member's task. During the task, team members were seated side by side, but they were separated by a barrier and thus could not view each other or the other team member's displays. Team members in the Full Shared Display condition were seated side by side with their computer monitors approximately six inches apart. This placement allowed them the ability to view the other team member's computer screen while performing the task.

After reading the instructions and at the completion of each trial, participants were given time to ask questions to clarify their tasks. In all conditions, team members could communicate with one another verbally during the task and were encouraged to determine what the other team member was doing, as well as work together on a joint strategy to improve performance during the task. Teams completed two 6-minute practice trials followed by nine 6-minute test trials (three at each workload level). Participants were given a 15 minute break after completing the first three test trials.

Task

The Theatre Defense program used in the previous research (Bolstad & Endsley, 1998) was modified for this study to include the Abstract Shared Display condition, varying sensor reliability, and two different missile types, as described in more detail below. The Theatre Defense microworld was written in Microsoft Visual Basic. It was based on Multitask, a single person control task created by Kaber and Endsley (1997). Theatre Defense was hosted on two separate Pentium based workstations that were connected by an Ethernet LAN. Data for each team member was recorded by the workstation computers.

Theatre Defense incorporates activities by two individuals: an Intelligence Officer and an Air Commander who each have separate, but inter-related tasks. The two team members work at separate workstations, connected by an Ethernet LAN. The role of the Air Commander is to protect the home base from incoming aircraft. Targets (designated by blank boxes) appear on the radar screen moving towards a central point (the home base), as shown in Figure 1. The Air Commander must prioritize these targets (based on range and speed) and request information from the

Intelligence Officer on their identity and mission priority as well as provide AWAC location information, which determines sensor reliability. Once an identification has been received from the Intelligence Officer, the Air Commander processes the targets accordingly. The Air Commander must choose which targets to destroy (based on range, speed, and penalty/reward points) and which to let through to the home base (such as friendlies).

Targets included fighter, bomber, and transport aircraft of either friendly or enemy designations, making for a possibility of six categories with a total of 16 different aircraft types. Points were assigned to each category representing the reward points for destroying the aircraft and penalty points for allowing the aircraft to get through to the home base. Reward and penalty points for each category were based on the mission relevance and lethality of the aircraft type. Friendly aircraft had a zero penalty for getting through to home base and a negative reward associated with destroying them. In addition to landing or destroying an aircraft, it was possible for some targets to collide with each other, resulting in the reward and penalty points associated with both aircraft to be recorded. Thus, the Air Commander needed to correctly destroy enemy aircraft that would conflict with friendly aircraft before such a collision occurred.

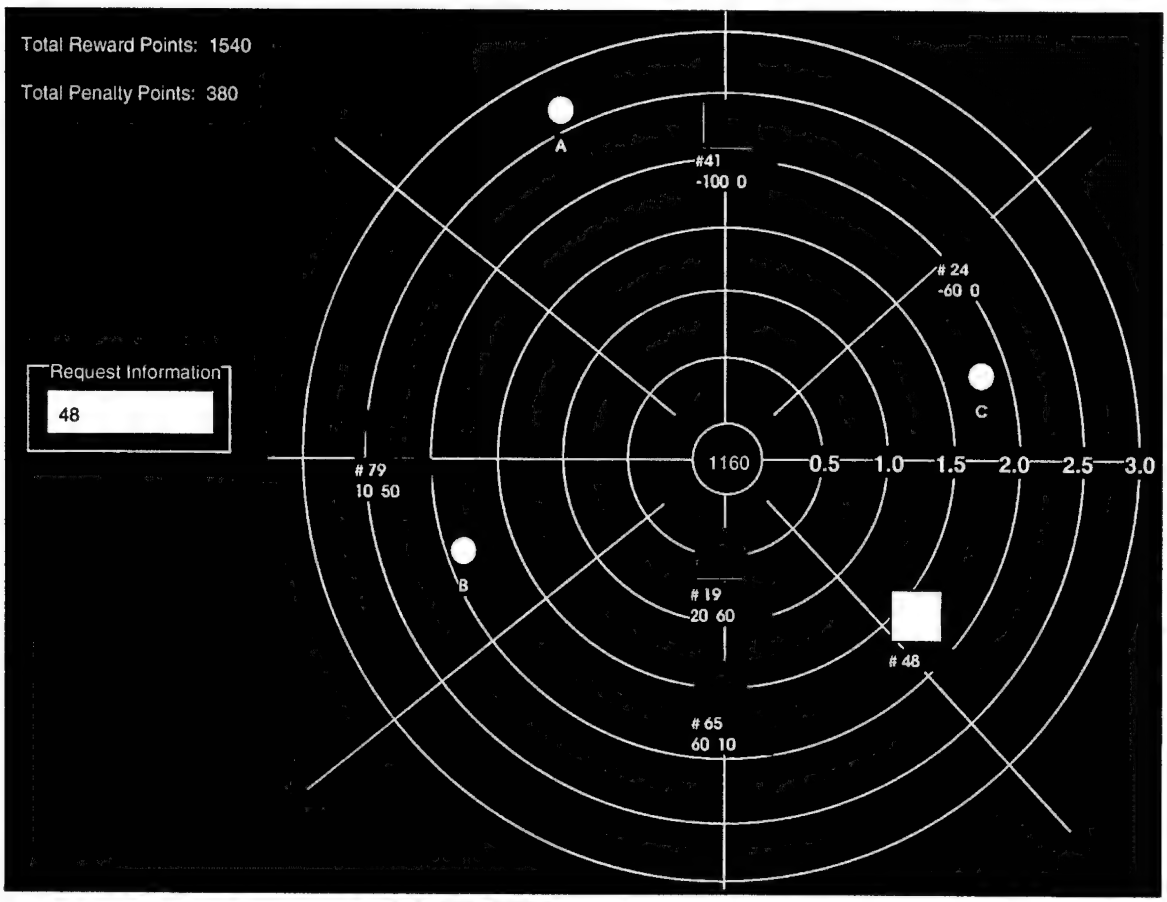

Figure 1. Air Commander Workstation's Screen

If the Air Commander decided to attack a target, he/she was required to choose which missile to launch for the attack. There were two types of simulated missiles available: a Sparrow which is smaller and faster and used for destroying fighters and an AMRAAM (advanced medium range air to air missile) which is a long range radar guided missile used for destroying bombers and transports. The left mouse button launched Sparrows and the right mouse button launched AMRAAMs. If the appropriate missile was launched, the plane was destroyed, however, if the incorrect missile was launched for the targeted aircraft, the chances that the plane would be destroyed were less than 50%.

The Intelligence Officer was supplied with a list of targets and the identifications provided by several different sensors, as shown in Figure 2. Upon a request from the Air Commander, the Intelligence Officer needed to select the sensor information for that target and make a designation of the target aircraft type and category. Three sensors (A, B, and C) mounted on mobile AWACS aircraft were provided. Participants were instructed that the sensor reliability rates were dependent upon their location and could either be 75%, 50%, or 25%. The Intelligence Officer could receive the current sensor reliability by requesting AWACS locations from the Air Commander or by the Air Commander providing it spontaneously.

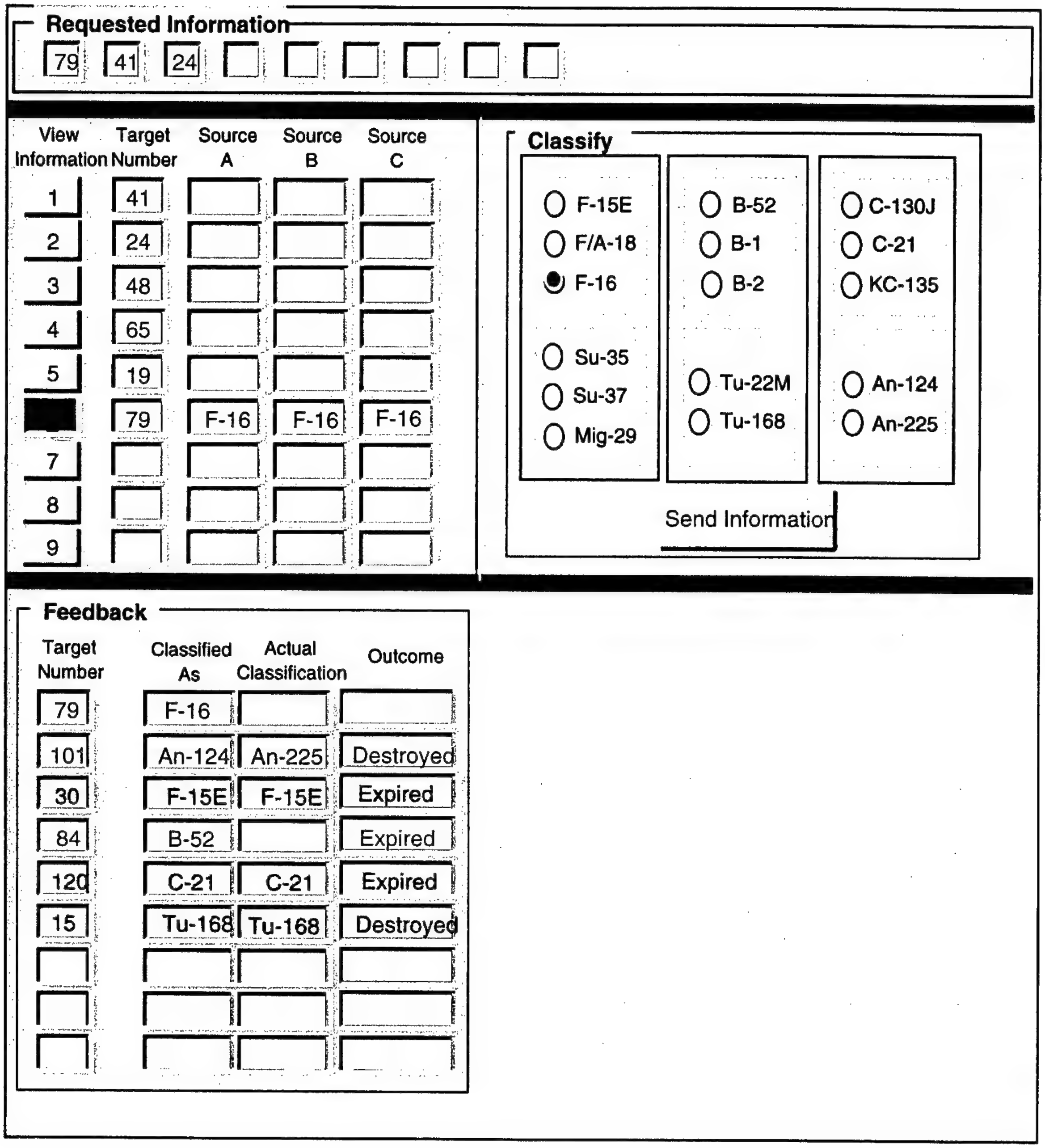

Figure 2. Intelligence Officer's Workstation Screen

To represent issues present in the real world, the information from the three sensors was either consistent (1/3 of the cases), partially missing (1/3 of the cases), or dissonant (1/3 of the cases). The distribution of the dissonant and missing information was distributed across sensor types and reliabilities. For instance, in some cases two sensors indicated a friendly and one an enemy, and in other cases two indicated an enemy and one a friendly. Which sensor provided the dissonant information was also counter-balanced across cases to provide for information on the effect of sensor reliability as well as sensor confirmation in making identification decisions.

Once the Intelligence Officer made a decision on aircraft identification, this information was passed to the Air Commander who saw the target change colors (indicating its category) and the reward and penalty points associated with the target (based on its type of classification). This information was dependent on the Intelligence Officer's identification and therefore may or may not have been correct. However, the points assigned when the target was processed (landed, destroyed, or collided) were based on the actual identification of the target. Feedback was provided to the Intelligence Officer only after the target was destroyed or allowed to pass through to the home base, as in the real world (e.g. F-16 passed through; F-16 destroyed). The Air Commander was also provided with the running point total. Learning, therefore, was able to take place allowing the team members to develop effective strategies and decision behaviors.

The pace of the task was such that to maximize points, both team members needed to be very strategic about how they prioritized and processed targets. Otherwise, a significant number of enemy aircraft would penetrate the air defense and strike the home base, or a significant number of friendly aircraft would fall prey to fratricide.

In the Non-Shared Display condition, each officer had only a limited amount of information from the other team member in addition to their own display. The Intelligence Officer saw only the prioritization list provided by the Air Commander and the Air Commander saw only the resultant classification provided by the Intelligence Officer. Any other exchange of information had to occur verbally.

In the Full Shared Display condition, each officer also saw all the display information of the other officer. Therefore, the Intelligence Officer also saw a picture of the Air Commander's radar display which it was hypothesized would help him/her better prioritize and anticipate the prioritization of the targets to be identified. It also allowed the Intelligence Officer to directly assess sensor reliability based on AWACS position, rather than having to request this information from the Air Commander.

The displays were modified in the Abstracted Shared Display condition to provide each officer with all the needed information from the other team member's display, based on an analysis of shared information requirements. In this condition, the Air Commander also received sensor data in the lower left corner of the screen as shown in Figure 3. This information was sent over to the Air Commander through a datalink capability after the Intelligence Officer identified each target.

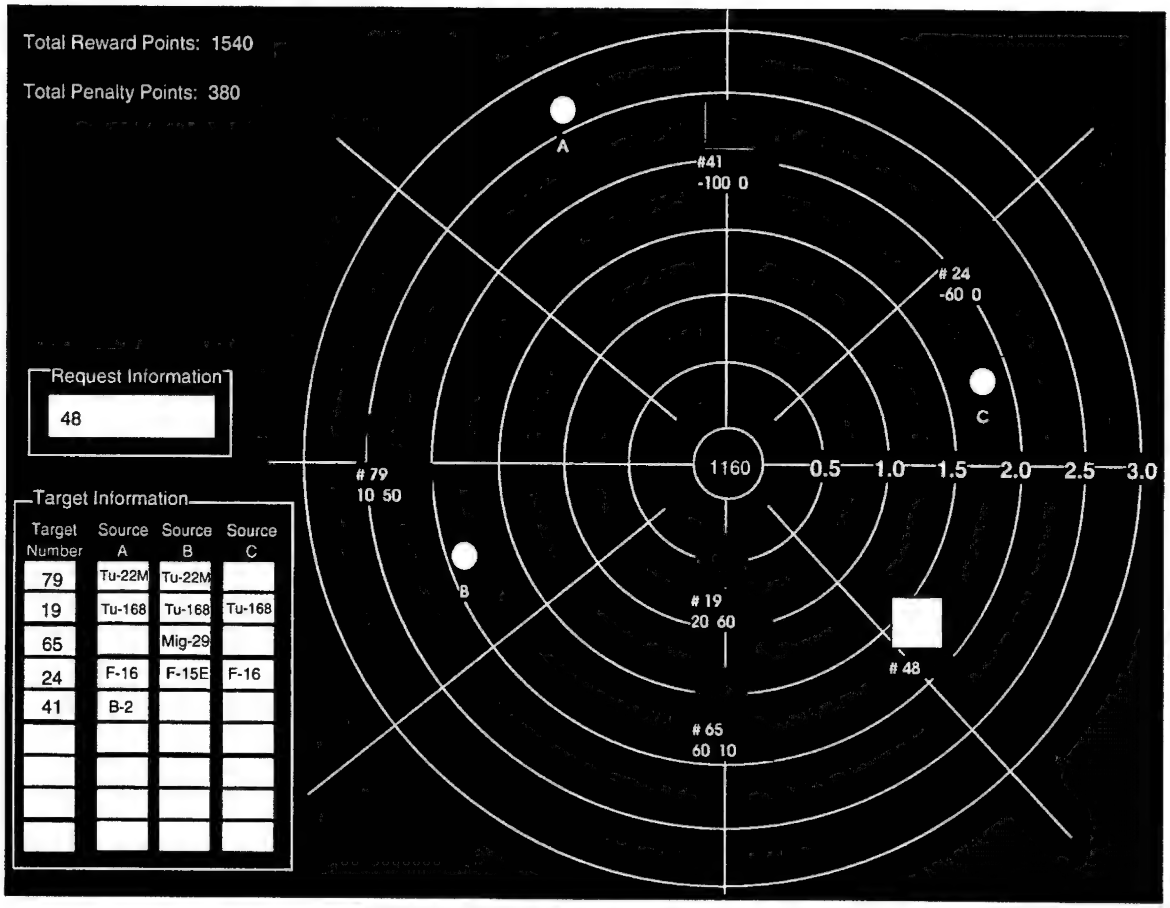

Figure 3. Air Commander Workstation's Screen - Abstract Shared Display

In the Abstracted Shared Display condition, the Intelligence Officer also received information on target proximity from home base in the lower right corner of the screen, as shown in Figure 4. The targets are listed from top to bottom with the top target being the closest to home base and the bottom target being the farthest. To the left of this display the sensor reliability information was shown, followed by the point totals.

It was hypothesized that the Abstracted Shared Displays would help both officers better perform their tasks by enhancing shared SA on this team task. It was hypothesized that the Full Shared Display condition would lower team performance, as was observed in the previous study. It was also hypothesized that the Full and Abstracted Shared Display conditions would lead to lower levels of team communication as less information would need to be verbally transferred from one officer to another. Finally, it was hypothesized that the task workload level would interact with all of these findings. Specifically, we expected that both the Full and Abstracted Shared Displays would have more of an effect under high workload conditions.

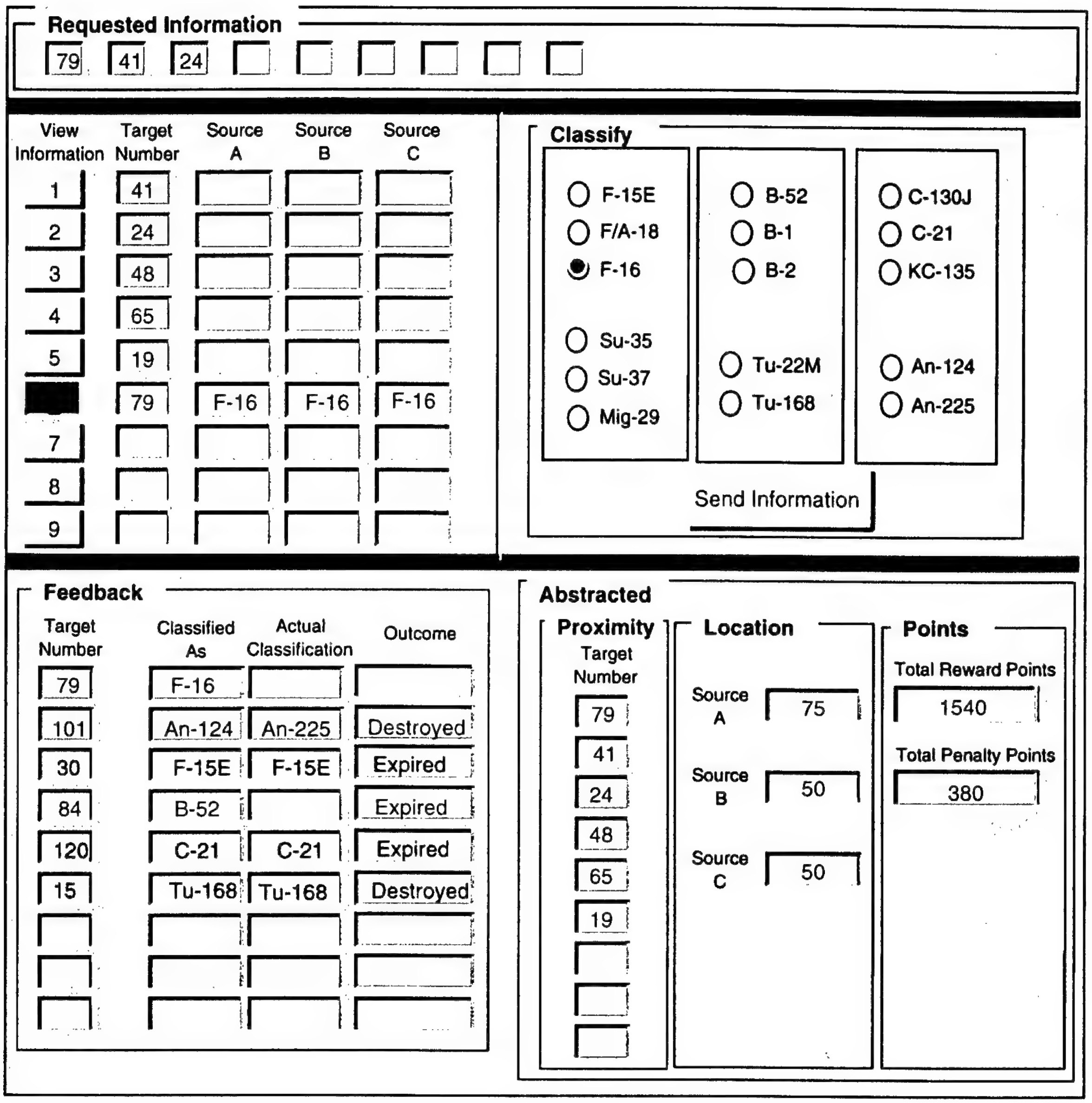

Figure 4. Intelligence Officer's Workstation Screen - Abstract Shared Display

RESULTS

Scoring

Data was collected from both participants during the trials. In order to facilitate data analysis (as each team produced more than 650 separate target entries), summary files were created containing means for the variables of interest for each of the nine trials for each team. Mean penalty points, mean reward points, and mean decision time to expiration, collision, or attack were calculated for each trial for each team. Mean time from target information request to classification, mean target viewing time, the percentage of targets that were requested by the Air Commander at time of

classification, and the percentage of targets that were at the top of the Air Commander's request list at the time of classification were also calculated for each trial for each team.

Three sets of analysis were conducted. The first examined the effects of Shared Display Type and Workload Level on team performance. The second analysis examined the influence of sensor performance, in particular dissonant data, on decision making. The final analysis examined the effects of Shared Display Type and Workload Level on the teams' verbal communications. All analyses were performed using analysis of variance (ANOVA). Tukey tests were used for post-hoc analysis. We used an alpha level of .05 for all analyses.

Shared Display Type and Workload

Penalty points, reward points, decision making time, percentage of targets classified from the request list, and percentage of targets classified from the top of the Air Commander's request list were each examined using an ANOVA which included Shared Display Type, Workload Level, and their interaction.

Penalty Points and Reward Points

Both the reward points, $F(2,153) = 8.68$, $p < .001$, and penalty points, $F(2,153) = 5.945$, $p = .003$, significantly varied across the three display conditions. Reward points were lowest in the Full Shared Display condition. The Non-Shared and Abstracted Shared Displays were similar in terms of reward points, as shown in Figure 5. Penalty points were highest in the Full Shared condition. Penalty points with the Abstracted Shared Display conditions were the least.

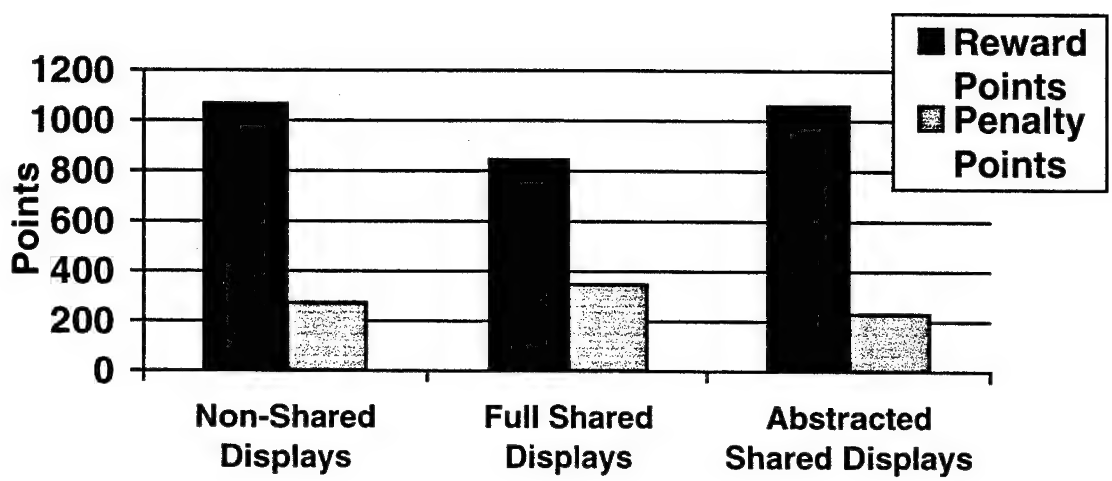

Figure 5. Mean Reward and Penalty Points by Shared Display Type

Thus, as compared to the Non-Shared Display condition (control), teams with the Full Shared Displays obtained both fewer reward points and more penalty points for overall worse performance. This confirms the findings of the previous study (Bolstad & Endsley, 1998). In comparison, teams with the Abstracted Shared Displays obtained about the same level of reward points as the control condition, without an increase in penalty points. In fact, their penalty points were slightly lower (although not significantly). The Abstracted Shared Display significantly out performed the Full Shared Display on both measures.

As expected, both reward, $F(2, 153) = 125.335, p < .001$, and penalty points, $F(2, 153) = 183.682, p < .001$, increased significantly from Workload Level three to Workload Level nine as shown in Figure 6. The number of reward and penalty points accrued is highly dependent on the number of aircraft appearing during the test. The higher the Workload Level, the greater the number of planes and hence the opportunities to accrue points. To better examine this variable, the reward and penalty points were normalized. The normalized score for each team was calculated as the percentage of reward or penalty points achieved by the team as a function of the amount possible during the trial.

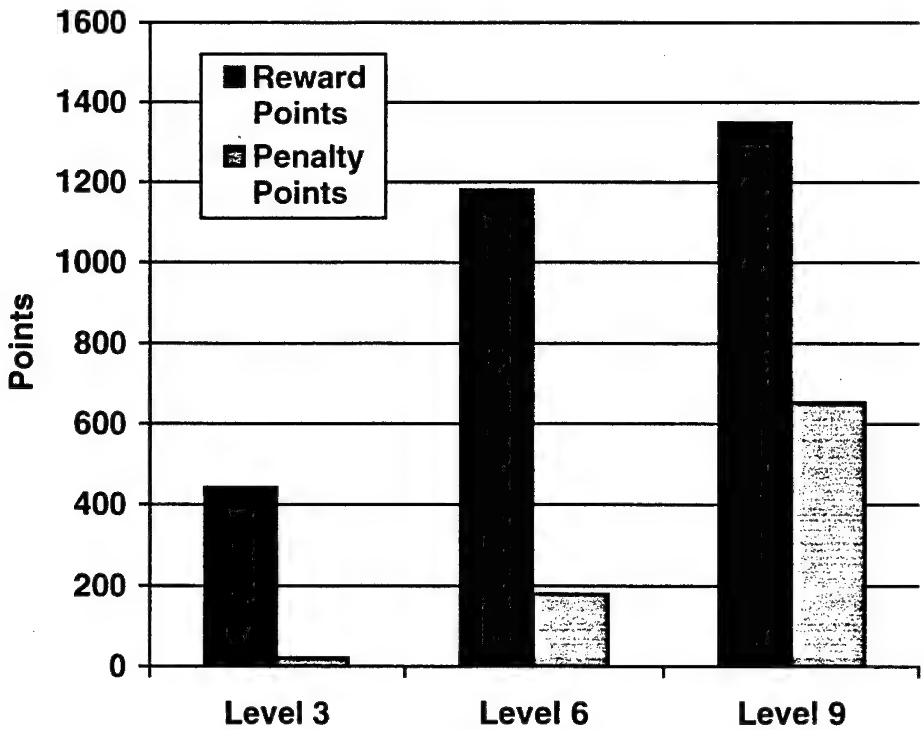

Figure 6. Mean Reward and Penalty Points by Workload Level

An analysis of these normalized scores showed that both the normalized reward points, $F(2, 153) = 3.17$, $p = .045$, and normalized penalty points $F(2, 153) = 7.359$, $p = .001$, were effected by Workload Level, as shown in Figure 7. They were significantly higher at a Workload Level of nine and lower at a Workload Level of three, as before. Thus, the changes in performance at different Workload Levels were not strictly due to the changed opportunities for scoring, but due to other changes in the teams' ability to carry out the tasks under the different loading conditions. At the High Workload Level, the teams began "shooting at everything," creating both proportionately higher rewards and higher penalties. At the Low Workload Level, they were able to be more careful and minimized penalties.

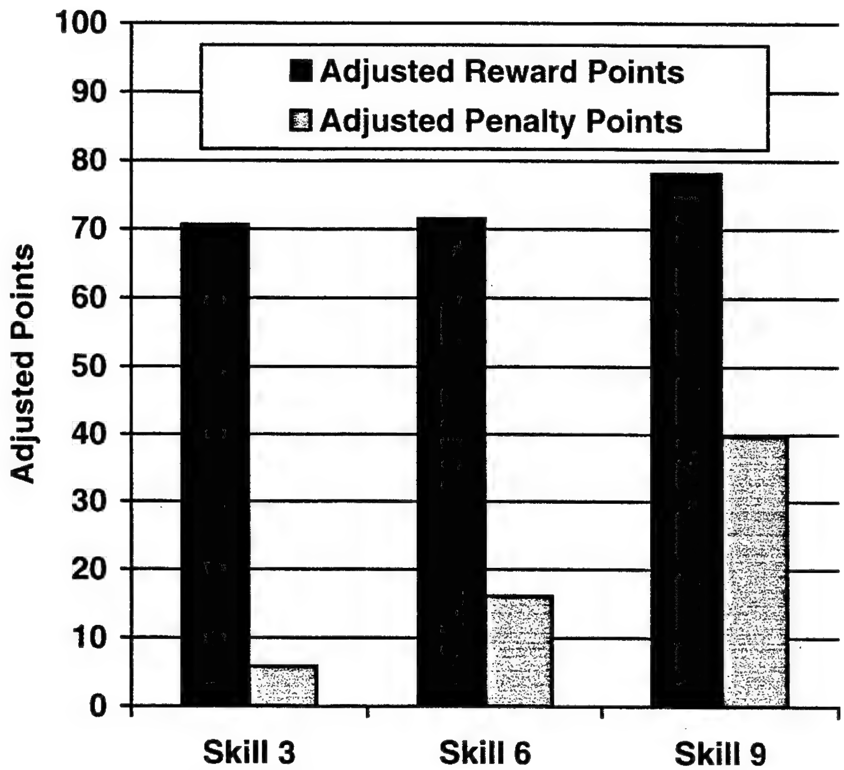

Figure 7. Mean Adjusted Reward and Penalty Points by Workload Level

The interaction of Shared Display Type and Workload Level was significant for both reward points, $F(4, 153) = 2.838$, $p = .026$, and penalty points, $F(4, 153) = 3.407$, $p = .011$. At the Low Workload Level, the number of reward and penalty points did not vary significantly across Shared Display Type conditions. This indicates that at Low Workload Levels, the presence or type of Shared Displays does not present either a problem or a significant boost to performance. This was not true for the Moderate and High Workload Levels, however.

As shown in Figure 8, while reward points were higher in the High Workload conditions, the increases were less for the Full Shared Display condition than for the Non-Shared and Abstracted Shared Display conditions. In fact, in the Full Shared Display condition, performance eventually plateaued at Workload Levels six and nine, at a performance level slightly lower than that observed for the Non-Shared Display condition at Workload Level six. Performance with the Abstracted Display condition did not show this problem, however, with the reward points essentially equal to that in the Non-Shared Display condition.

As shown in Figure 9, the penalty points were also higher in the Full Shared Display condition at the Highest Workload Level. Penalty points were actually lower with the Abstracted Shared Display at the Moderate and High Workload Levels as compared to the two other Shared Display conditions. Thus, it can be seen that the Full Shared Display created a particular problem at the Higher Workload Levels. The Abstracted Shared Display, on the other hand, allowed penalty reduction at the Higher Workload Levels.

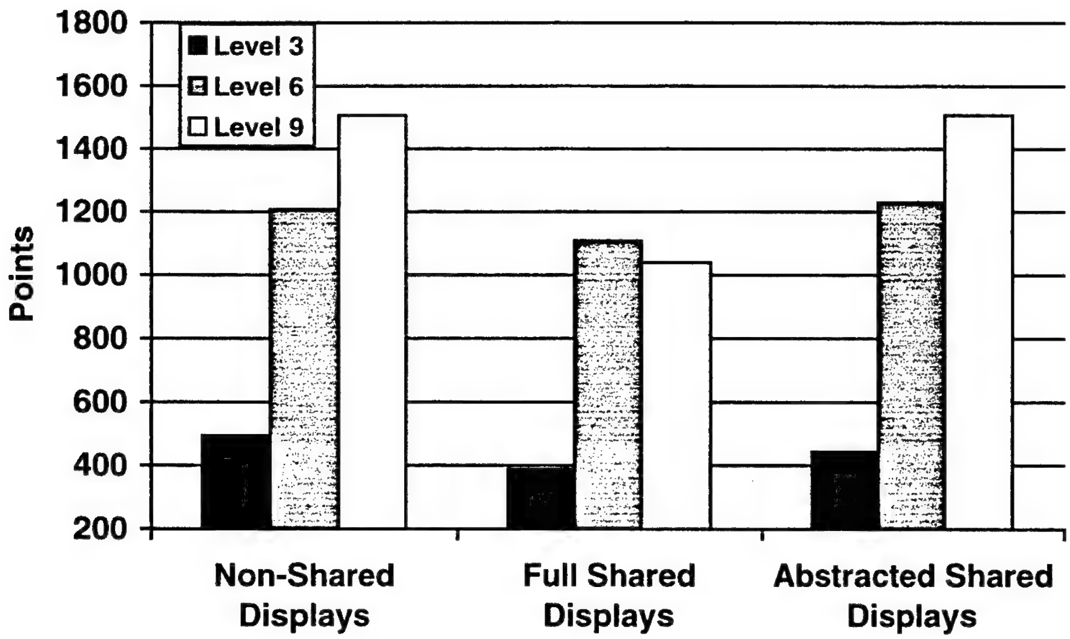

Figure 8. Mean Reward Points by Shared Display Type and Workload Level

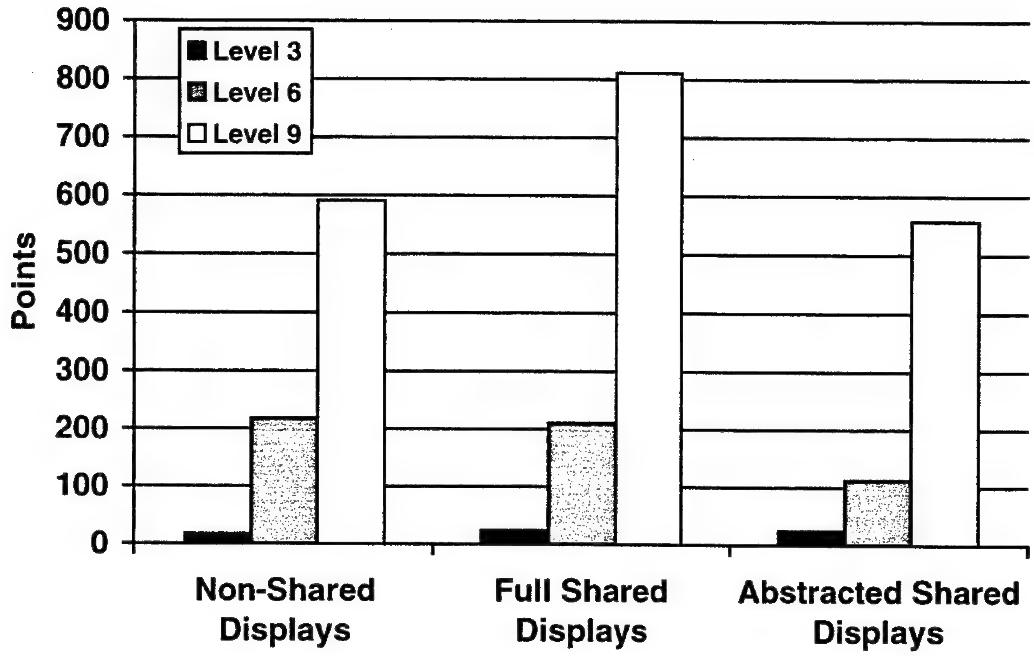

Figure 9. Mean Penalty Points by Shared Display Type and Workload Level

Decision Time

Shared Display Type also significantly effected team decision times. When the Intelligence Officers were given either the Full Shared Display or Abstracted Shared Display, they were significantly slower in making target classifications, $F(2, 143) = 8.821, p < .001$, as can be seen in Figure 10. The Intelligence Officer may have been slowed down by the presence of the additional target information from either the Full Shared Display or Abstracted Shared Display.

Shared Display Type also significantly effected the time it took the Air Commander to attack, $F(2, 153) = 7.359$ $p < .001$, shown in Figure 10. They took the longest time to make a decision with the Abstracted Shared Display, most likely due to the need to consider more information. Surprisingly, this was not the case with the Full Shared Display. This may be because the Air Commanders were not using the information on the Full Shared Display in many cases due to overload. The greater likelihood of using the information provided in the Abstracted Display condition was realized in the better performance for these teams, even though the Air Commander took longer to make attack decisions.

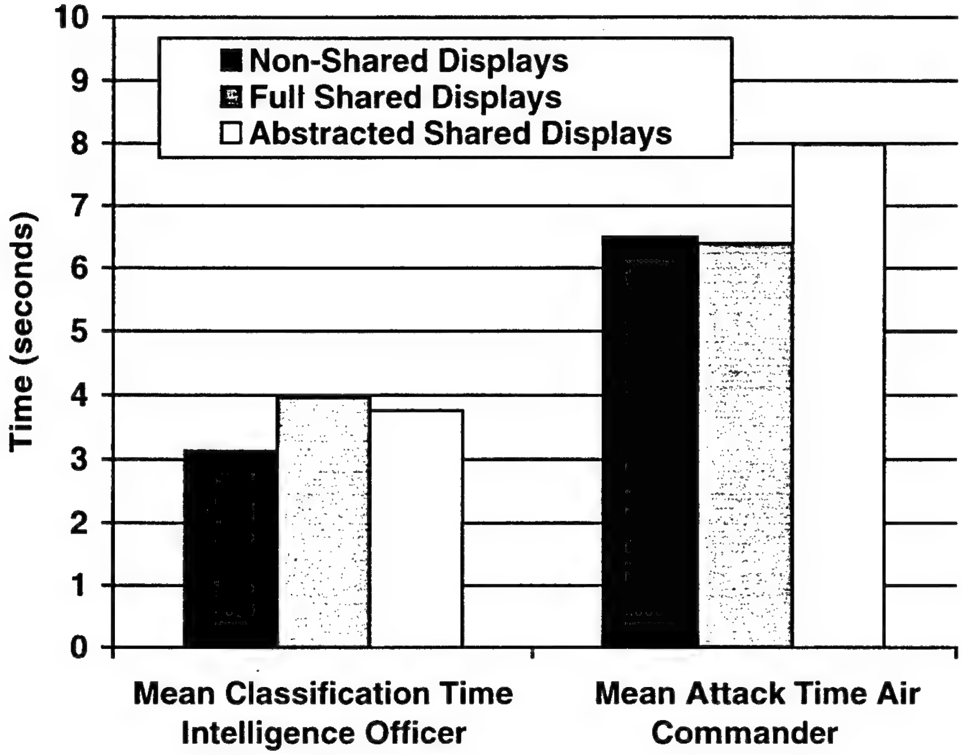

Figure 10. Mean Decision Time by Shared Display Condition

As the Workload Level increased, the Intelligence officer took significantly less time to make aircraft classifications, $F(2,143) = 45.19$, $p < .001$. That is, as they had more aircraft to deal with, they made each decision more quickly since they had to make more decisions in the same time period. The Air Commander took longer to make the decision to attack aircraft at Higher Workload Levels, $F(2,146) = 21.437$, $p < .001$, as shown in Figure 11. Although they had slightly more time due to the faster target classification of the Intelligence Officer, they also had many more aircraft to contend with. The long decision time by the Air Commanders at the Higher Workload Levels most likely reflects the fact that as they got more "loaded up," it took them longer to get to each aircraft. They could not process each one as it was classified on their screen. In addition, under High Workload, they often started using the wrong missiles, which slowed down their performance.

Finally, there was also a significant Shared Display Type by Workload Level interaction for the time it took the Intelligence Officer to classify the aircraft, $F(4,143) = 3.221$, $p < .001$. The interaction was due to significantly longer classification times at the Lowest Workload Level for the Full Shared Display and Abstract Shared Display conditions. This effect is shown in Figure 12. Under the Low Workload Level, participants really used the time available to acquire extra information from the Shared Displays. This effect was less evident at the Moderate and High Workload Levels.

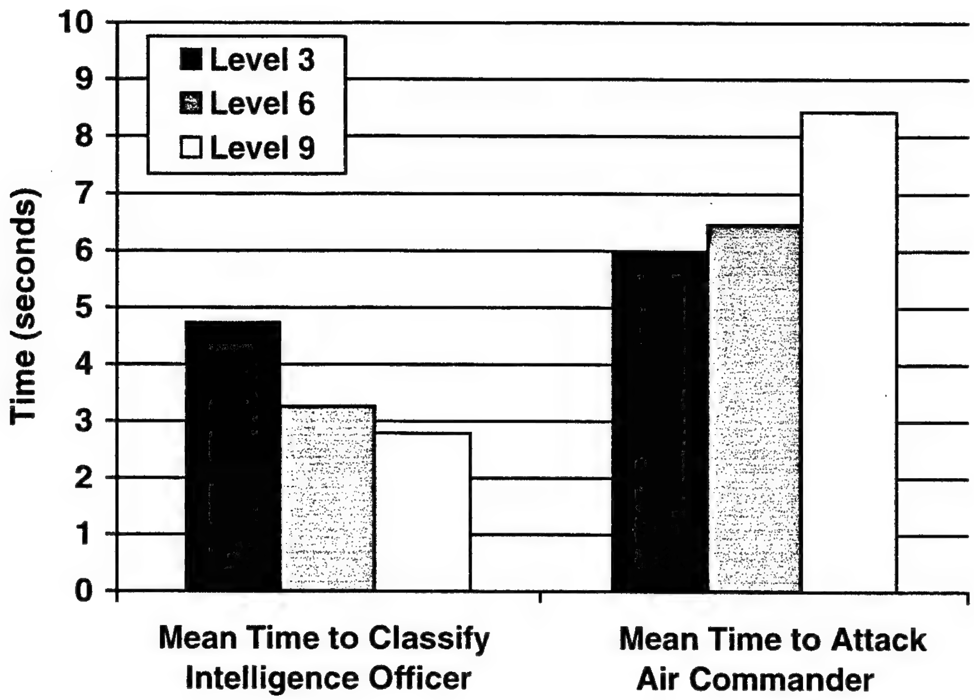

Figure 11. Mean Decision Time by Workload Level

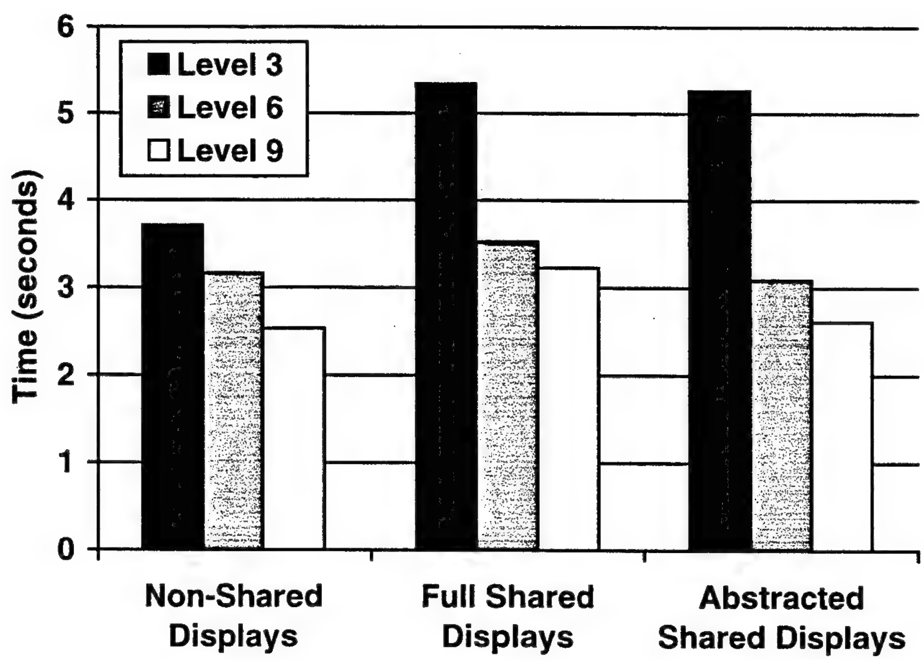

Figure 12. Mean Classification Time by Display Type and Workload Level

Classification of Priority Targets

The degree to which the Intelligence Officer classified targets that the Air Commander had requested was examined as an index of the degree to which the two participants were operating as a team. The percentage of targets classified that were on the request list was significantly effected by Shared Display Type, $F(2,149) = 20.66$, $p < .001$, and Workload Level, $F(2,149) = 14.511$, $p < .001$. These effects are shown in Figure 13.

Over 50 percent of the targets categorized had been requested by the Air Commander (on the request list) in the Full Shared Display condition and fewer than 20 percent had been requested in the other two conditions. While it is possible that participants may have requested the target identifications verbally, the analysis of verbal interactions does not bear out this possibility (see page 19). It therefore indicates very limited team interaction in the Non-Shared Display condition. The provision of the Full Shared Displays greatly increased team coordination, as evidenced by this factor, although at a decrement to performance. The Abstracted Shared Display condition did not show such an effect, however. It is most likely that in this condition, they were able to get the information participants needed from the Abstracted Shared Displays directly, and therefore had less need to communicate this information formally. Unlike in the Non-shared Display condition, however, overall team performance was higher.

Participants also categorized the largest percentage of requested targets at the lowest workload level. Air Commanders were less likely to request the needed information at the higher workload levels or Intelligence Officers were less likely to attend to these requested prioritizations. Thus the team members operated more independently in these conditions.

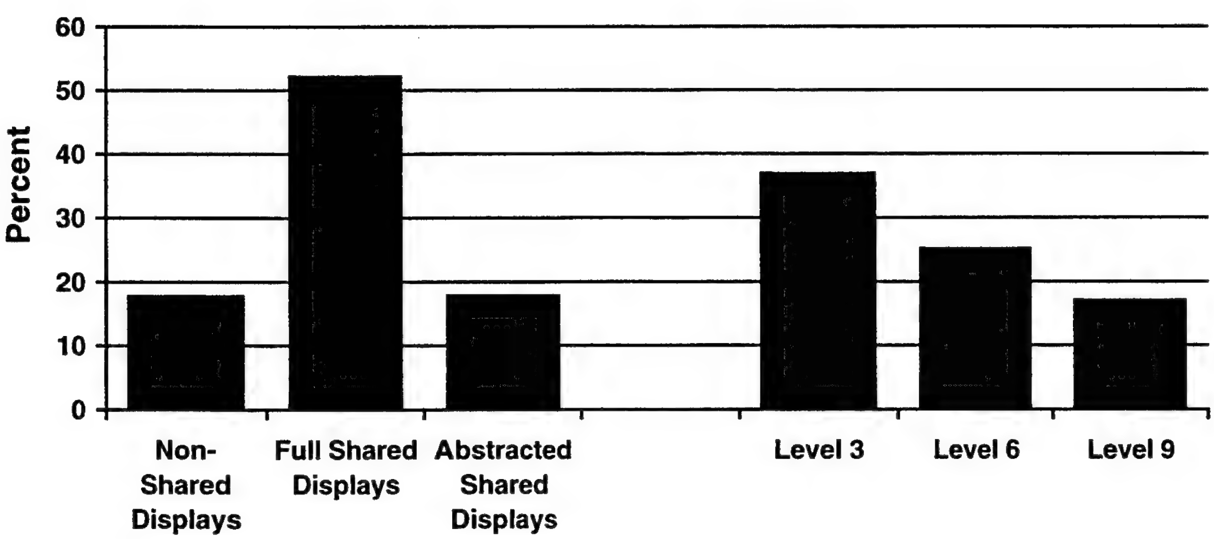

Figure 13. Percent of Targets Categorized that were Requested by the Air Commander

Similarly, the percentage of targets classified that were at the top of the request list (the highest priority) was significantly affected by Shared Display Type, $F(2,149) = 10.832$ $p < .001$, and Workload Level, $F(2, 149) = 17.529$, $p < .001$. There was also a significant Display Type by Workload Level interaction for this variable, $F(4,149) = 2.674$, $p = .034$, shown in Figure 14. More targets were classified from the top of the request list in the Full Shared Display condition, in particular at the lowest workload level, than with any other Shared Display Type or Workload Level combination.

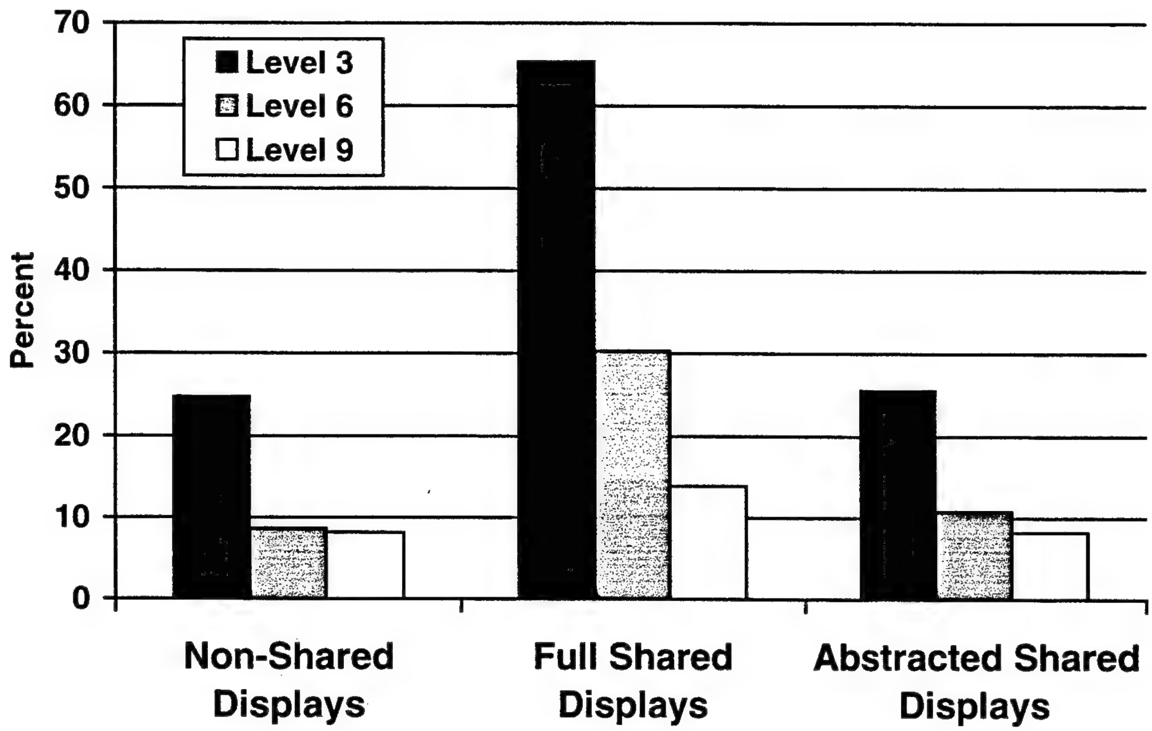

Figure 14. Percent of Targets Categorized from the Top of the Request List

Verbal Communications Analysis

The second analysis focused on the effects of Shared Display Type and Workload Level on the verbal communication that occurred between team members. During the test, a tally was kept of the type of verbal exchange occurring between team members. For this analysis, communications were recorded separately for three categories (1) information provided from the Intelligence Officer to the Air Commander, (2) information provided from the Air Commander to the Intelligence Officer, and (3) joint communications that involved discussions between the two team members. In addition, within each of these categories, requests and provisions of aircraft identification were tallied separately from other communications (as the former could be expected to change as a function of workload level), creating a total of 6 communication categories.

The requesting of information about aircraft identification by the Air Commander varied by Workload Level, F(2,45) = 6.518, p=.003. As shown in Figure 15, they needed to request significantly more aircraft identifications as the number of aircraft increased. There were no changes in this variable as a function of Shared Display Type. There were also no changes in the verbal provision of aircraft identification by the Intelligence Officer or joint communications about target identification as a function of Workload Level or Shared Display Type.

In terms of other information communications, there was a significant change in the degree to which the Air Commander provided information to the Intelligence Officer in the two Shared Display conditions, $F(2,45) = 13.78$, $p = .000$. As shown in Figure 16, there was information (such as sensor reliability) directly from the shared displays and required less verbal communications. Workload level did not have a significant affect on this variable. There were no significant changes in the number of other verbal communications from the Intelligence Officer to the Air commander or in joint communications as a function of Shared Display Type or Workload Level.

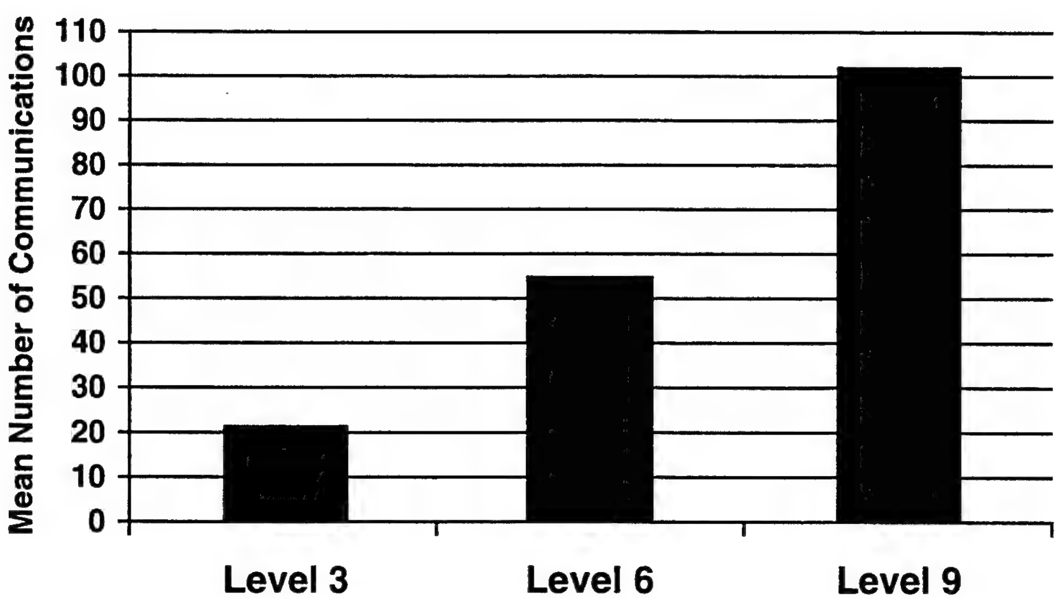

Figure 15. Mean Number of Requests for Aircraft Identification from Air Commander

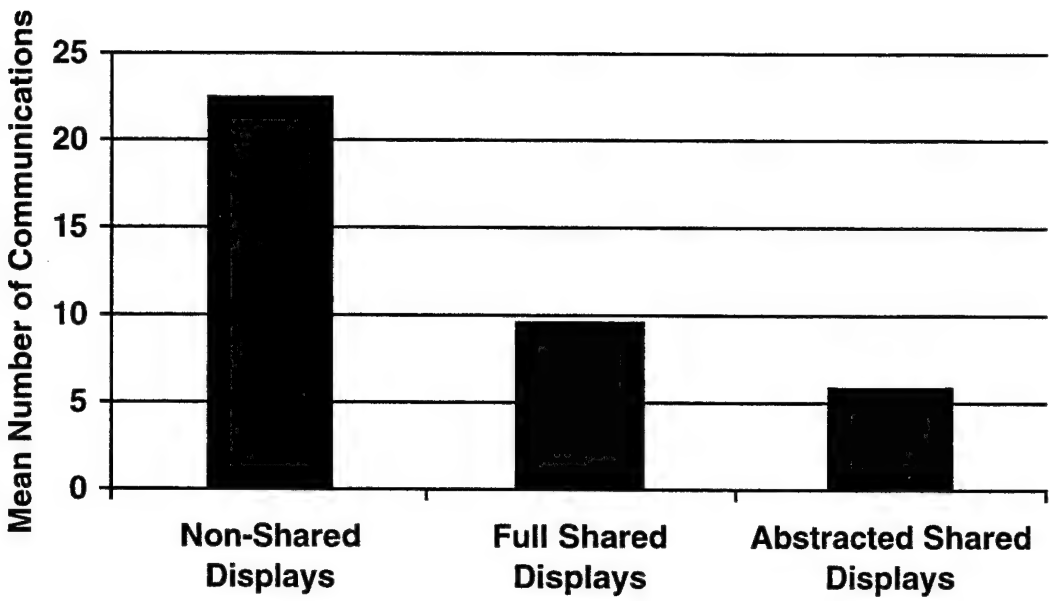

Figure 16: Number of Communications from the Air Commander to the Intelligence Officer

Sensor Performance

The third analysis examined the effect of the sensor performance (all sensors reporting, missing data, dissonant data), sensor pattern (which sensor was missing or dissonant), and sensor reliability on the decision making of the Intelligence Officer.

Sensor Pattern Analysis

During the study, the Intelligence Officer would view the available sensor information to determine each aircraft's classification. Sensor Performance was either full (all three sensors reporting the same identification), missing (one of the three sensors not reporting), or dissonant (one of the three sensors reporting a different identification from the other two). Four Sensor Patterns were presented for missing and dissonant data: Sensor A missing or dissonant, sensor B missing or dissonant, sensor C missing or dissonant, and sensors B and C missing or dissonant from sensor A. First, an ANOVA of Sensor Performance by Sensor Pattern was performed on both the mean viewing time and correctness of classification by the Intelligence Officer.

Mean viewing time was significantly effected by the Sensor Performance, $F(2,204) = 12.824$, $p < .001$, but not Sensor Pattern. The Intelligence Officers took significantly longer to make a classification decision for dissonant data.

The correctness of the classification decision was significantly effected by both the Sensor Performance and the Sensor Pattern. Intelligence Officers incorrectly classified targets with dissonant sensor data more frequently than they did those with full or missing sensor data, $F(2, 204) = 167.674$, $p < .001$. Surprisingly, missing sensor data was not a significant problem for

classification performance, contrary to a sensor that showed dissonant data. It should be noted that a missing sensor could have reported either the same or dissonant information, therefore it had the same potential for dissonance. The Intelligence Officers did not appear to take this into account, however. The pattern of the dissonant or missing sensor also had an effect, $F(3,204) = 18.091$, $p < .001$, with worse performance when sensor A was dissonant, but correct.

The sensor performance by sensor pattern interaction was also significant, $F(6,204) = 13.02$, $p < .001$. The interaction appears to be primarily driven by the dissonant data, as shown in Figure 17. They performed the worst when the dissonant data was presented on sensor A, the first in the list. Under these conditions, the Intelligence Officer correctly identified the aircraft less than 20% of the time. These results are similar to that found in the earlier study (Bolstad & Endsley, 1998), however, interesting differences are present. The overall classification accuracy was worse overall under sensor dissonance and the degree of problem experienced when sensor A was dissonant was greater.

The main difference between the two studies was that the sensors in this study had varying reliability as a function of the location of the AWACS, while in the previous study, the reliability remained constant for each sensor. A further analysis was therefore conducted to examine the effects of the sensor reliabilities on the strategies used by the Intelligence Officers for dealing with dissonant data.

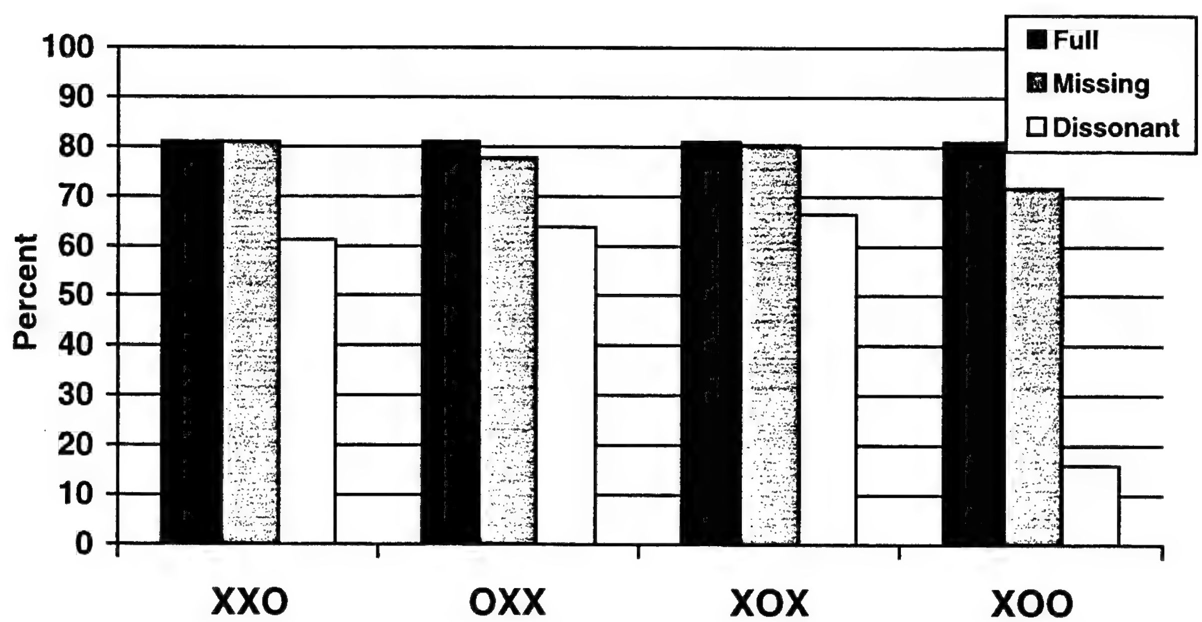

Figure 17. Correctness of Classification by Sensor Performance and Sensor Pattern

Sensor Reliabilities

We conducted a further analysis on the classification strategies utilized by the Intelligence Officers as a function of the relative reliabilities of the sensors. We wished to determine the degree to which the Intelligence Officers were taking sensor reliability into account versus the degree to which they were relying on other heuristics, such as reliance on the first sensor in the list, or on the identification supported by most sensors, regardless of reliability.

There were five different cases of dissonance analyzed. In all cases of information dissonance, at least two sensors reported the same identification (majority) and the other sensor was different (minority). The five possibilities are depicted in Table 2.

Table 2. Sensor Reliability Possibilities

	Majority *Sensor Data Aircraft is X*	**Majority** *Sensor Data Aircraft is X*	**Minority** *Sensor Data Aircraft is Y*
CASE 1 *Rankings of Sensor Reliabilities*	1 1 1	2 2 3	2 3 2
CASE 2 *Rankings of Sensor Reliabilities*	2	2	1
CASE 3 *Rankings of Sensor Reliabilities*	1	1	2
CASE 4 *Rankings of Sensor Reliabilities*	1	2	1
CASE 5 *Rankings of Sensor Reliabilities*	1	1	1

(Case 1) One of the majority sensors has the highest reliability and the other two have lower reliabilities.

(Case 2) Both majority sensors have the same reliability, but the minority sensor has the highest reliability.

(Case 3) Both majority sensors have the same reliability and it is higher than the reliability of the minority sensor.

(Case 4) The minority sensor and one majority sensor have the highest reliability and the other majority sensor is of lower reliability.

(Case 5) All sensors have the same reliability.

The Intelligence Officer's classification strategies based on these cases is shown in Figure 18. In the first case, one of the majority sensors was also always the one with the highest reliability. Therefore, these two strategies are not discriminable in this case. They accounted for the majority, over 90%, of the classifications. This same pattern dominated Case 3, in which both majority sensors had the same reliability and it was higher than that of the minority sensor. Very few other strategies were observed in these cases.

In Case 4, the minority sensor and only one of the majority sensors had the highest reliability (e.g. F/A-18-75%, F16-75%, F16-50%). The other majority sensor was of lower reliability. In this case, both choices were of the highest reliability. In examining whether participants chose the minority or majority sensor recommendation in this case, it appears that they were far more likely to choose the identification of the majority sensor (68%), than that of the minority sensor (28%), although not an insignificant number chose the identification of minority sensor.

Case 2 allowed discrimination between the strategies of choosing the majority or the most reliable sensor. In this case, the minority sensor had the highest reliability (e.g. F16-50%, F/A-18-25%, F/A-18-25%). Decision behavior appeared close to chance in this ambiguous case, with the likelihood of selecting the identification of the more highly reliable minority sensor (49%) roughly equaling the likelihood of selecting the identification of the less reliable majority sensors (47.5%).

Case 5, in which the sensors all had equal reliability, also created difficulties for decision making. While the most frequent strategy observed in this case was to adopt the recommendation of the majority sensor (79%), many people also followed the minority sensor (18%).

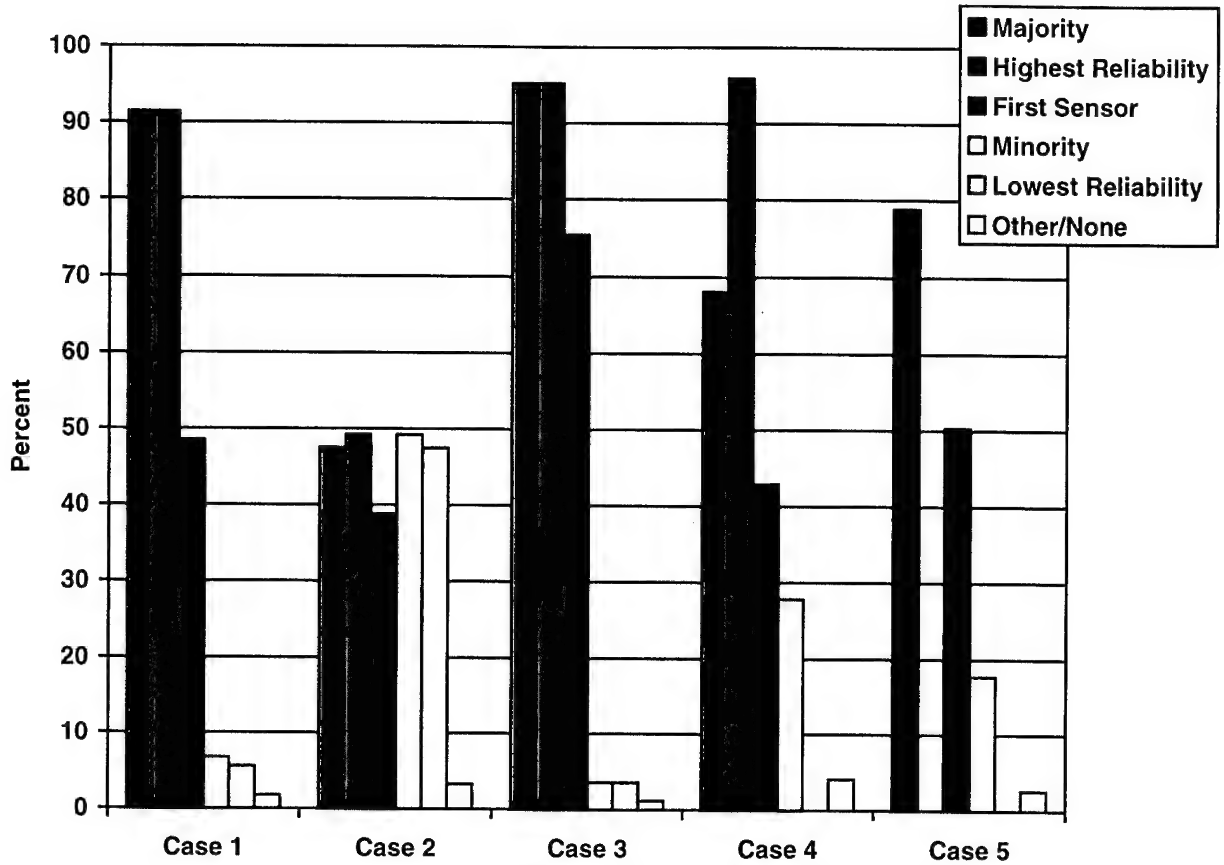

Figure 18. Strategies Used in Dealing with Information Dissonance

Overall, it appears that participants did take sensor reliability as well as sensor confirmation into account in their decision processes. In comparison, a simpler strategy of picking the recommendation of the first sensor in the list (A) was not supported by the data. In Cases 1 and 5, selection of the recommendation of the first sensor was at chance levels and also indistinguishable from that expected by the strategy of selecting the majority sensor (of the two choices, there was a 50% chance of the majority sensor choice being in place A). In Case 2 and Case 4, participants were significantly less likely than chance to have picked the recommendations of the first sensor (p<.001). In these cases when the first sensor was not the dissonant sensor, participants were less likely than would be expected to have selected its recommendations. Thus, sensor reliability and sensor confirmation rather than sensor position appeared to dominate the strategies used. In Case 3, the opposite was found. Participants were more likely than expected to have picked the recommendations of the first sensor, which is odd considering that the first sensor was dissonant more of the time in these cases (p<.001). Sensor reliability appeared to be a more important consideration in dealing with dissonance.

Finally, we examined the degree to which the Workload Level or Shared Display Type may have affected strategy selection in this task. Shared Display Type had a significant effect on the strategies used. An examination of Figure 19 shows that while the trends are the same across conditions, there was more of a tendency to rely on high reliability sensors in the Non-Shared

Display condition ($\chi2$ = 10.7, p < .01), and an increased tendency to rely on the majority sensors in the Full Shared and Abstracted Shared Display conditions ($\chi2$ = 7.09, p < .05). They were also more likely to use other strategies (or not classify targets) under the Full Shared Displays Condition ($\chi2$ = 16.7, p < .001).

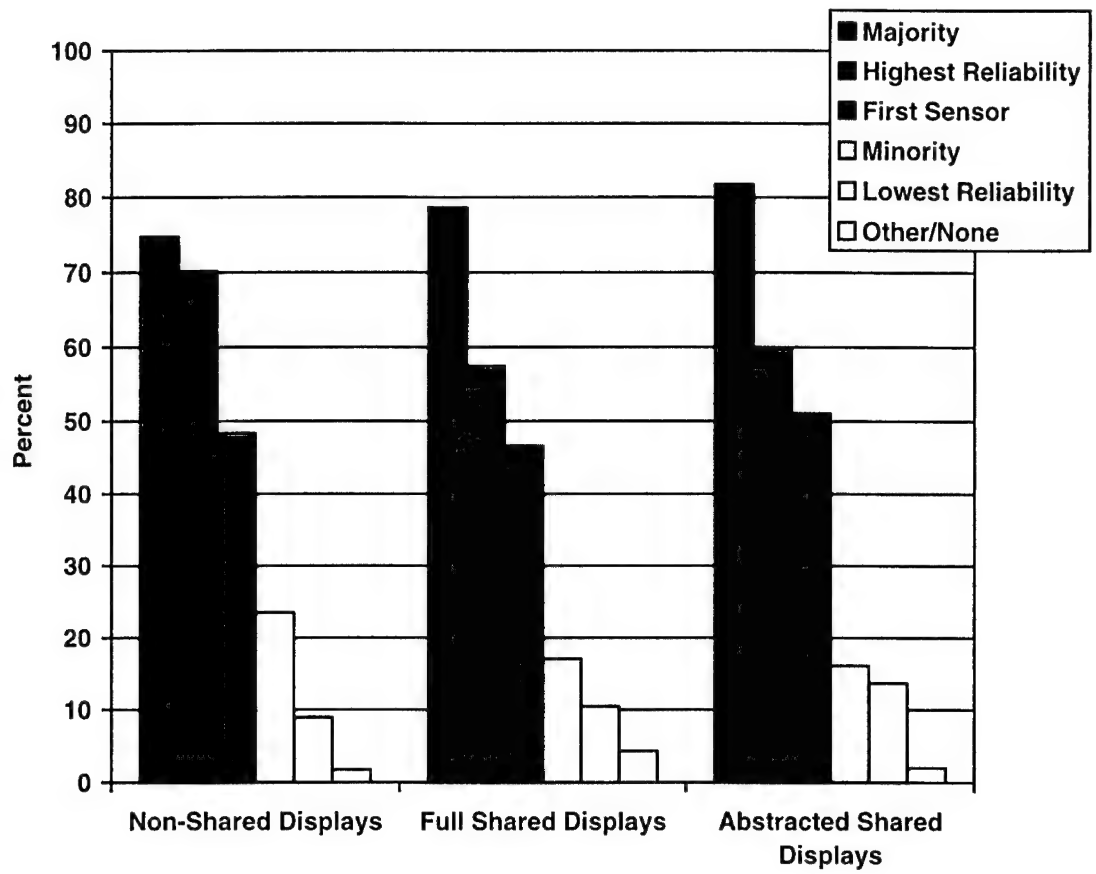

Figure 19. Strategy by Shared Display Type

Workload level also significantly affected identification strategy, Figure 20. There was less of a tendency to rely on the more reliable sensors under high workload ($\chi2$ = 12.01, p < .01), and a greater tendency to use the first sensor under low workload ($\chi2$ = 8.48, p < .05). They appeared to use other strategies (or not classify targets) more often under high workload ($\chi2$ = 23.2, p < .001).

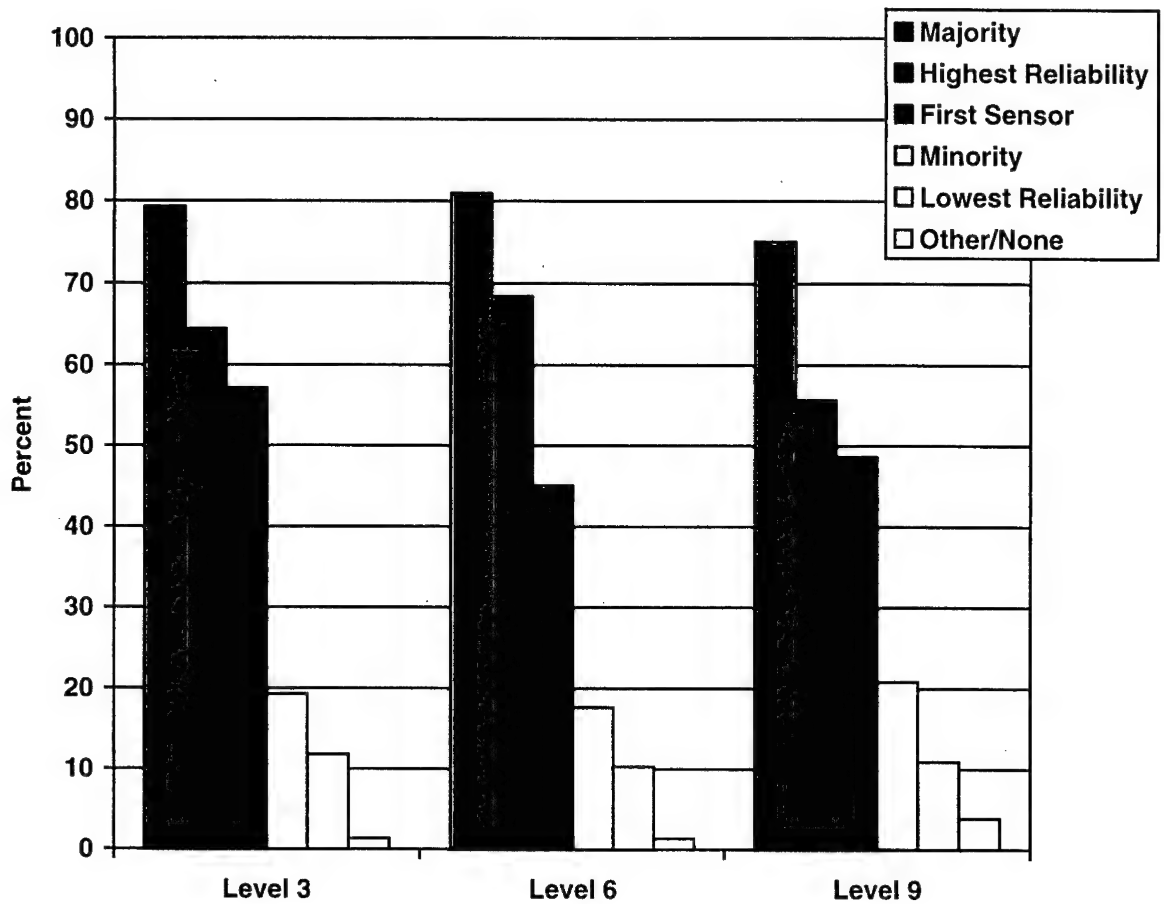

Figure 20. Strategy by Workload Level

DISCUSSION

This study indicates that the way in which people use Shared Displays is actually quite complex and related to both task strategies used and workload level. As compared to a situation in which no shared display is available, providing Full Shared Displays induced lower reward and higher penalty points overall. Examination of the data shows that these displays were problematic particularly under high workload levels. The extra information served to hinder performance under high workload.

The Abstracted Shared Displays provided more of the benefits, with less of the problems of the Full Shared Displays. The penalty points were lower than with Shared Displays, particularly the moderate and high workload levels.

Under low workload levels, no performance enhancements or problems were found associated with either of the Shared Display types. Under these conditions, participants were able to achieve the needed team SA using purely verbal communications. It is expected that as task complexity increases, doing so will be harder and harder, however. As Workload Level increased, the Abstracted Shared Displays proved to be a particular benefit, outperforming both the Non-Shared and Full Shared Display conditions.

Interestingly, the means by which this occurred was not so readily discernable. An increase in the degree to which the Intelligence Officers were following the Air Commander's prioritization list was not evident and overall verbal communications from the Air Commander to the Intelligence Officer decreased in the Abstracted Shared Display condition, compared to the other display conditions. Other verbal communications remained unchanged between the display conditions. It can only be speculated that these two indices of overt team communication were rendered unnecessary by the improved information sharing which was possible with the Abstracted Shared Display.

The use of an abstracted display also seems to decrease the need for team interaction. Teams using abstracted displays requested fewer targets and had overall lower level of verbal exchanges. These teams may have had enough sufficient information to perform their task and only request information from the Intelligence Officer when they need verification. On the other hand, teams using verbal displays never developed a mental model of the other persons task and therefore did not fully understand how the team functions. These teams had fewer requests for target classifications and a greater number of verbal exchanges. However, they may not have fully understood what information their team member needed and were passing irrelevant information.

By varying workload level we hoped to further understand how the strategies used by teams change as the workload level increases (from three aircraft to nine aircraft) and create more team interaction. What we found was a greater increase in both penalty and reward points as the task got more difficult, which was true for all the display types. Teams had the greatest opportunity to accrue points as the workload level increased. They also made the largest number of errors and overall performance decreased. There was also less team interaction as workload increased.

Thus, it can be said that this study serves to further confirm certain aspects of the team SA model. Namely, team SA can be supported through shared displays and one can compensate for the other in achieving the team SA needed to support joint task performance. The use of Abstracted Shared Displays over Full Shared Displays is supported by this research, particularly under high workload levels.

Secondly, the performance of participants in making decisions in the face of information dissonance was further explored. Like the previous study, we found that dissonant data is handled very differently than missing data. The Intelligence Officer took significantly longer to make classifications with missing or dissonant data. We also wanted to determine if participants were relying on the sensor reliabilities to determine classification when data is dissonant. It was found that with varying sensor reliabilities, participants relied upon strategies that took account of both the reliability of the sensors and the presence of confirming sensors in making their decisions.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, this study supported the use of shared displays for enhancing team performance. The design of these displays needs to be carefully constructed, however, to provide each team member with just the pertinent information required to maintain team SA. That is, it needs to be constructed based upon an analysis of the team members shared SA requirements. This finding supports the first component of the team SA model.

Secondly, it was found the degree to which team members will function as a team and will benefit from shared displays is dependant on their workload level. At low levels of workload, team processes and verbal communications may be dependent for forming the needed team SA. At moderate and higher workload levels, teams will be negatively affected by shared displays that provide too much information, but positively affected by shared displays that provide just that information needed for shared SA.

Finally, this study shed additional light on the handling of information dissonance in command and control type tasks. Specifically, dissonant information was found to both slow performance and decrease performance accuracy. Participants were sensitive to both sensor reliability and sensor confirmation in making their decisions; however, the ambiguity present in these situations was hard to overcome with their decision strategies.

Overall, this study confirmed and expanded on the previous research on team SA. Team SA and performance in team tasks can be greatly enhanced by the development of shared displays that are based on the shared information requirements of team members. More research is needed to find ways to combat the observed problems in handing information dissonance. In addition, more research is needed to expand these results to more realistic tasks and battlefield conditions.

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APPENDIX A : Intelligence Officer Job Description for Non-Shared Display and Full Shared Displays

Overview

In this study we are interested in understanding how individual and team decision making occurs in the warfare environment. Unlike the wars fought in the earlier part of this century, future battles will have individuals working together that are separated by great distances, such as continents. Thus, the transfer and understanding of information between teams will be critical to mission success.

During this task you will be asked to make decisions that are similar to ones faced by individuals during a military operation. You will be assigned to either the position of air commander or intelligence officer (Intel officer). Your battle ground is the air space over your home base. You will be working together to defeat the enemy. It is the air commander's job to ensure that the home base is protected from enemy aircraft. The air commander will be viewing these aircraft on a display similar to a radar screen. The Intel officer's job entails providing the air commander with information on these same aircraft that are detected by the sensors. Your success will depend upon how well the overall team performs.

This task is hosted on two separate computer workstations. You will be asked to sit at one of these workstations while wearing a set of headphones. We will first begin with a training period followed by 3 trials of approximately 6 minutes each. You may request a break at any time between trials and you will be given a 15 minute break during the middle of the test. This will be followed by a second test period of 6 more trials. If you have any questions regarding the following task instructions please ask them before the testing begins. You will get to practice before testing begins and may also ask questions during practice.

Intelligence Officer

The United States has just learned that Ikestan attacked a U.S. base in the middle east. The president has ordered all military personnel in the surrounding areas to be on alert for possible attacks. You are stationed at an air base in Western Europe. A few hours after the initial attack you are instructed to report to your post as enemy aircraft are making their way towards a U.S. base in N. Africa. Aircraft have been sent to intercept and destroy these incoming planes. It is your job to provide the air commander at this N. African base with target identification information on these incoming aircraft.

You will be providing requested target information. You will be shown a list of aircraft target numbers that are within this base's airspace. It is your job to decide on target identifications and to send this information to the air commander.

You may see 6 different types of aircraft: friendly fighters, enemy fighters, friendly bombers, enemy bombers, friendly transports, and enemy transports. There are a total of 16 different kinds of aircraft that are in use by friendly and enemy forces as shown in the table below.

Plane Categories	Types
Friendly Fighters	F/A-18 F-15E F-16
Friendly Bombers	B-52 B-1 B-2
Friendly Transports	C-130J C-21 KC-135
Enemy Fighters	Mig-29 Su-35 Su-37
Enemy Bombers	Tu-22M Tu-168
Enemy Transports	An-124 An-225

Your station contains a set of head phones and the information screen that is shown on the following page. Targets whose ID are requested are shown in the box at the top of the screen labeled 'Requested Information' in order of priority. You need to monitor this section of your screen as the target numbers will be continually changing as targets land, are destroyed, or appear in your air space.

You will have access to sensor data about these targets. The screen will display each sensors best assessment of the target's ID, which may not always be correct. It is up to you to determine the true aircraft identification, so use your best judgment. You can access sensor data for a target by clicking on the 'View Information' button that corresponds to the target number or by pressing a the number on the keyboard that corresponds to the button number on the screen. However, you may only see sensor data for one target at a time.

The sensors are labeled 'Source A', 'Source B', and 'Source C'. AWACS, also known as reconnaissance planes, are providing you with this information. The reliability of the sensor information is dependent upon their location, the closer the plane to home base (center of the grid), the more reliable the information. Remember to use these reliabilities when determining target identification. Be aware that not all sensors may report information on a particular target. For instance, Sensors B and C may have information on the first target requested, but not sensor A. Thus, you may have to make your decision on partial information.

Once you have viewed the sensor data, you need to indicate the aircraft's identification by selecting the aircraft type on the right side of your screen. All the possible aircraft are listed there. After you have selected an ID, click on the 'Send Information' button to send this information to the air commander.

The bottom part of the screen will provide you with information regarding the outcome of the battle. It will display the aircraft number and its actual ID as well as the final result for the plane; destroyed, got through, or collided. This feedback will give you information regarding your classification of the aircraft. If you misclassified a plane, the "Classified As" and "Actual Type" box will display two different airplanes and the text will appear in red. If you correctly classified an aircraft, the text will appear in blue. If the plane was not classified prior to resolution, it will appear in green text. Use this information to help you better identify the aircraft. There will be a delay between making your ID and receiving this feedback, as true ID and disposition cannot be determined until the plane has either landed or been destroyed.

Sensor data for aircraft will continually appear on your information screen until the testing time is up. Thus, you could potentially process hundreds of planes in the 6 minutes allotted for the task. Please be aware that this task moves quickly. We want you to work as quickly and as accurately as you can.

APPENDIX B : Intelligence Officer Job Description for Abstract Shared Displays

Overview

In this study we are interested in understanding how individual and team decision making occurs in the warfare environment. Unlike the wars fought in the earlier part of this century, future battles will have individuals working together that are separated by great distances, such as continents. Thus, the transfer and understanding of information between teams will be critical to mission success.

During this task you will be asked to make decisions that are similar to ones faced by individuals during a military operation. You will be assigned to either the position of air commander or intelligence officer (Intel officer). Your battle ground is the air space over your home base. You will be working together to defeat the enemy. It is the air commander's job to ensure that the home base is protected from enemy aircraft. The air commander will be viewing these aircraft on a display similar to a radar screen. The Intel officer's job entails providing the air commander with information on these same aircraft that are detected by the sensors. Your success will depend upon how well the overall team performs.

This task is hosted on two separate computer workstations. You will be asked to sit at one of these workstations while wearing a set of headphones. We will first begin with a training period followed by 3 trials of approximately 6 minutes each. You may request a break at any time between trials and you will be given a 15 minute break during the middle of the test. This will be followed by a second test period of 6 more trials. If you have any questions regarding the following task instructions please ask them before the testing begins. You will get to practice before testing begins and may also ask questions during practice.

Intelligence Officer

The United States has just learned that Ikestan attacked a U.S. base in the middle east. The president has ordered all military personnel in the surrounding areas to be on alert for possible attacks. You are stationed at an air base in Western Europe. A few hours after the initial attack you are instructed to report to your post as enemy aircraft are making their way towards a U.S. base in N. Africa. Aircraft have been sent to intercept and destroy these incoming planes. It is your job to provide the air commander at this N. African base with target identification information on these incoming aircraft.

You will be providing requested target information. You will be shown a list of aircraft target numbers that are within this base's airspace. It is your job to decide on target identifications and to send this information to the air commander.

You may see 6 different types of aircraft: friendly fighters, enemy fighters, friendly bombers, enemy bombers, friendly transports, and enemy transports. There are a total of 16 different kinds of aircraft that are in use by friendly and enemy forces as shown in the table below.

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Enemy Bombers	Tu-22M Tu-168
Enemy Transports	An-124 An-225

Your station contains a set of head phones and the information screen that is shown on the following page. Targets whose ID are requested are shown in the box at the top of the screen labeled 'Requested Information' in order of priority. You need to monitor this section of your screen as the target numbers will be continually changing as targets land, are destroyed, or appear in your air space.

Target location is also provided in the lower right part of your screen. The target numbers are ordered according to their proximity to the home base. The closest target is at the top of the list and the farthest is at the bottom of the list.

You will have access to sensor data about these targets. The screen will display each sensors best assessment of the target's ID, which may not always be correct. It is up to you to determine the true aircraft identification, so use your best judgment. You can access sensor data for a target by clicking on the 'View Information' button that corresponds to the target number or by pressing the number on the keyboard that corresponds to the button number on the screen. However, you may only see sensor data for one target at a time.

The sensors are labeled 'Source A', 'Source B', and 'Source C'. AWACs, also known as reconnaissance planes, are providing you with this information. The reliability of the sensor information is dependent upon their location, the closer the plane to home base (center of the grid), the more reliable the information. The reliabilities of the sensors is shown in the lower right corner or your screen. The reliabilities will either be 25%, 50%, or 75%. Remember to use these reliabilities when determining target identification. Be aware that not all sensors may report information on a particular target. For instance, Sensors B and C may have information on the first

target requested, but not sensor A. Thus, you may have to make your decision on partial information.

Once you have viewed the sensor data, you need to indicate the aircraft's identification by selecting the aircraft type on the right side of your screen. All the possible aircraft are listed there. After you have selected an ID, click on the 'Send Information' button to send this information to the air commander.

The bottom part of the screen will provide you with information regarding the outcome of the battle. It will display the aircraft number and its actual ID as well as the final result for the plane; destroyed, got through, or collided. This feedback will give you information regarding your classification of the aircraft. If you misclassified a plane, the "Classified As" and "Actual Type" box will display two different airplanes and the text will appear in red. If you correctly classified an aircraft, the text will appear in blue. If the plane was not classified prior to resolution, it will appear in green text. Use this information to help you better identify the aircraft. There will be a delay between making your ID and receiving this feedback, as true ID and disposition cannot be determined until the plane has either landed or been destroyed.

Your overall team success is determined by the number of reward and penalty points you accrue. Point assignments have been made for each type of aircraft representing the reward points for destroying the aircraft and the penalty points for allowing the aircraft to land at your home base. This information is provided in the lower right corner of your screen.

Sensor data for aircraft will continually appear on your information screen until the testing time is up. Thus, you could potentially process hundred of planes in the 6 minutes allotted for the task. Please be aware that this task moves quickly. We want you to work as quickly and as accurately as you can.

APPENDIX C : Air Commander Job Description for Non-Shared Display and Full Shared Displays

Overview

In this study we are interested in understanding how individual and team decision making occurs in the warfare environment. Unlike the wars fought in the earlier part of this century, future battles will have individuals working together that are separated by great distances, such as continents. Thus, the transfer and understanding of information between teams will be critical to mission success.

During this task you will be asked to make decisions that are similar to ones faced by individuals during a military operation. You will be assigned to either the position of air commander or intelligence officer (Intel officer). Your battle ground is the air space over your home base. You will be working together to defeat the enemy. It is the air commander's job to ensure that the home base is protected from enemy aircraft. The air commander will be viewing these aircraft on a display similar to a radar screen. The Intel officer's job entails providing the air commander with information on these same aircraft that are detected by the sensors. Your success will depend upon how well the overall team performs.

This task is hosted on two separate computer workstations. You will be asked to sit at one of these workstations while wearing a set of headphones. We will first begin with a training period followed by 3 trials of approximately 6 minutes each. You may request a break at any time between trials and you will be given a 15 minute break during the middle of the test. This will be followed by a second test period of 6 more trials. If you have any questions regarding the following task instructions please ask them before the testing begins. You will get to practice before testing begins and may also ask questions during practice.

Air Commander

The United States has just learned that Ikestan attacked a U.S. base in the middle east. The president has ordered all military personnel in the surrounding areas to be on alert for possible attacks. You are stationed at an air base in Tenya, N. Africa, which has been put on alert. A few hours after the initial attack you are instructed to report to your post as enemy aircraft are making their way towards your base. Aircraft have been sent to intercept and destroy these incoming planes. It is your job to protect your base from enemy aircraft strikes while allowing your planes to land safely.

Your success is determined by the number of reward and penalty points you accrue. You will want to maximize your reward points and minimize your penalty points. In order to do this, you will need to determine which aircraft are friendly and which are enemy and what type of aircraft they are. At the same time, you will need to prioritize incoming targets based upon their range from your home base and speed to determine which aircraft are the most critical at any one time. You will request aircraft identity information from the Intel officer (who is at an airbase in Western Europe) to support this prioritization decision.

Point assignments have been made for each type of aircraft representing the reward points for destroying the aircraft and the penalty points for allowing the aircraft to land at your home base. The points are based on the mission relevance and lethality of the aircraft. For example, transports can carry many personnel and therefore could present a great threat if they land at a U.S. base, while the loss of a U.S. transport would be a devastating blow to our forces. Friendly aircraft have a zero penalty for getting through to home base (you would want them to safely land at home) and a negative reward associated with destroying it (you would not want to destroy your own planes). Enemy aircraft, however, have both positive reward and penalty points.

In addition, it is possible for some targets to collide with one another. If two friendly aircraft collide no points are accrued for this. If two enemy aircraft collide, the highest reward points of the two aircraft are given. However, if a friendly and an enemy aircraft collide, you receive double the penalty points of the enemy aircraft. Therefore, it is in your best interest to destroy enemy aircraft before they collide with friendly planes.

You will see 6 different types of aircraft: friendly fighters, enemy fighters, friendly bombers, enemy bombers, friendly transports, and enemy transports. There are a total of 16 different kinds of aircraft that are in use by friendly and enemy forces. Below is a table of these aircraft, their color appearance on your radar screen once identified, and their associated reward and penalty points.

Plane Categories	Types	Color	Reward Points	Penalty Points
Friendly Fighters	F/A-18	Blue	-20	0
	F-15E	Blue	-40	0
	F-16	Blue	-60	0
Friendly Bombers	B-52	Green	-50	0
	B-1	Green	-80	0
	B-2	Green	-100	0
Friendly Transports	C-130J	Turquoise	-120	0
	C-21	Turquoise	-140	0
	KC-135	Turquoise	-150	0
Enemy Fighters	Mig-29	Red	60	10
	Su-35	Red	80	20
	Su-37	Red	100	10
Enemy Bombers	Tu-22M	Orange	10	50
	Tu-168	Orange	20	60
Enemy Transports	An-124	Yellow	50	50
	An-225	Yellow	60	60

You will view the aircraft on a radar screen, similar to that shown on the following page. Your home base is at the center of the screen. The aircraft will appear from outside the radar and travel inward towards your home base. It is your job to let the friendly aircraft land at the base, but the enemy aircraft must be destroyed before reaching the base. An aircraft will get through if left alone (it will land on its own).

You destroy aircraft by launching missiles at them. There are two types of missiles available; a Sparrow which is smaller and faster and used for destroying fighters and AMRAAM (advanced medium range air to air missiles) which are long range radar guided missiles used for destroying bombers and transports. To launch missiles at an aircraft, use the computer mouse to click on it once; the left mouse button launches Sparrows and the right mouse button launches AMRAAMs. This gives the command to launch missile defense resources against the target. The target will turn a light violet color to indicate that it has been targeted. If you launch an inappropriate missile at an aircraft, the plane may not be destroyed and you will have to try again.

AWACS, also known as reconnaissance planes, will also be present on your screen. They are small blue circles labeled A, B, or C. It is their job to determine plane identifications and relay this information to the Intel Officer. The reliability of the AWAC information is dependent upon their location, the closer the plane to home base (center of the grid), the more reliable the information. At 5 to 10 miles out (first two rings) the reliability is 75% at 15 to 20 miles the reliability is 50% and at 25 to 30 miles the reliability is 25%.

Initially, all aircraft appear as white squares. Below each square is the aircraft target number and its speed. In order for you to determine what type of aircraft is on your radar, you must request this information from the intelligence officer. This is done by typing the aircraft's number in the request box in the lower left corner of the radar screen. All you need to do is type in each number followed by the return key. The Intel officer will receive and process your information. It's identity will be shown by the color of the square on your radar screen (ex. blue for friendly fighters). The aircraft number will remain the same, but the penalty points for the identification that has been made will appear below the target number. This may or may not be correct depending on the accuracy of the ID. You must decide what to do with each aircraft, either processing it (destroying it) or letting it land at the base. At all times during this task, your total reward and penalty points are shown at the top left corner of your radar screen.

Aircraft will continually appear on your radar screen until the testing time is up. Thus, you could potentially process hundreds of planes in the 6 minutes allotted for each session. Please be aware that this task moves quickly. We want you to work as quickly and as accurately as you can. These instructions may seem a bit confusing, so we will start with several training sessions to help clarify your task.

APPENDIX D : Air Commander Job Description for Abstract Shared Displays

Overview
In this study we are interested in understanding how individual and team decision making occurs in the warfare environment. Unlike the wars fought in the earlier part of this century, future battles will have individuals working together that are separated by great distances, such as continents. Thus, the transfer and understanding of information between teams will be critical to mission success.

During this task you will be asked to make decisions that are similar to ones faced by individuals during a military operation. You will be assigned to either the position of air commander or intelligence officer (Intel officer). Your battle ground is the air space over your home base. You will be working together to defeat the enemy. It is the air commander's job to ensure that the home base is protected from enemy aircraft. The air commander will be viewing these aircraft on a display similar to a radar screen. The Intel officer's job entails providing the air commander with information on these same aircraft that are detected by the sensors. Your success will depend upon how well the overall team performs.

This task is hosted on two separate computer workstations. You will be asked to sit at one of these workstations while wearing a set of headphones. We will first begin with a training period followed by 3 trials of approximately 6 minutes each. You may request a break at any time between trials and you will be given a 15 minute break during the middle of the test. This will be followed by a second test period of 6 more trials. If you have any questions regarding the following task instructions please ask them before the testing begins. You will get to practice before testing begins and may also ask questions during practice.

Air Commander

The United States has just learned that Ikestan attacked a U.S. base in the middle east. The president has ordered all military personnel in the surrounding areas to be on alert for possible attacks. You are stationed at an air base in Tenya, N. Africa, which has been put on alert. A few hours after the initial attack you are instructed to report to your post as enemy aircraft are making their way towards your base. Aircraft have been sent to intercept and destroy these incoming planes. It is your job to protect your base from enemy aircraft strikes while allowing your planes to land safely.

Your success is determined by the number of reward and penalty points you accrue. You will want to maximize your reward points and minimize your penalty points. In order to do this, you will need to determine which aircraft are friendly and which are enemy and what type of aircraft they are. At the same time, you will need to prioritize incoming targets based upon their range from your home base and speed to determine which aircraft are the most critical at any one time. You will request aircraft identity information from the Intel officer (who is at an airbase in Western Europe) to support this prioritization decision.

Point assignments have been made for each type of aircraft representing the reward points for destroying the aircraft and the penalty points for allowing the aircraft to land at your home base. The points are based on the mission relevance and lethality of the aircraft. For example, transports can carry many personnel and therefore could present a great threat if they land at a U.S. base, while the loss of a U.S. transport would be a devastating blow to our forces. Friendly aircraft have a zero penalty for getting through to home base (you would want them to safely land at home) and a negative reward associated with destroying it (you would not want to destroy your own planes). Enemy aircraft, however, have both positive reward and penalty points.

In addition, it is possible for some targets to collide with one another. If two friendly aircraft collide, no points are accrued for this. If two enemy aircraft collide, the highest reward points of the two aircraft are given. However, if a friendly and an enemy aircraft collide, you receive double the penalty points of the enemy aircraft. Therefore, it is in your best interest to destroy enemy aircraft before they collide with friendly planes.

You will see 6 different types of aircraft: friendly fighters, enemy fighters, friendly bombers, enemy bombers, friendly transports and enemy transports. There are a total of 16 different kinds of aircraft that are in use by friendly and enemy forces. Below is a table of these aircraft, their color appearance on your radar screen once identified, and their associated reward and penalty points.

Plane Categories	Types	Color	Reward Points	Penalty Points
Friendly Fighters	F/A-18	Blue	-20	0
	F-15E	Blue	-40	0
	F-16	Blue	-60	0
Friendly Bombers	B-52	Green	-50	0
	B-1	Green	-80	0
	B-2	Green	-100	0
Friendly Transports	C-130J	Turquoise	-120	0
	C-21	Turquoise	-140	0
	KC-135	Turquoise	-150	0
Enemy Fighters	Mig-29	Red	60	10
	Su-35	Red	80	20
	Su-37	Red	100	10
Enemy Bombers	Tu-22M	Orange	10	50
	Tu-168	Orange	20	60
Enemy Transports	An-124	Yellow	50	50
	An-225	Yellow	60	60

You will view the aircraft on a radar screen, similar to that shown on the following page. Your home base is at the center of the screen. The aircraft will appear from outside the radar and travel inward towards your home base. It is your job to let the friendly aircraft land at the base, but the enemy aircraft must be destroyed before reaching the base. An aircraft will get through if left alone (it will land on its own).

You destroy aircraft by launching missiles at them. There are two types of missiles available; a Sparrow which is smaller and faster and used for destroying fighters and AMRAAM (advanced medium range air to air missiles) which are long range radar guided missiles used for destroying bombers and transports. To launch missiles at an aircraft, use the computer mouse to click on it once; the left mouse button launches Sparrows and the right mouse button launches AMRAAMs. This gives the command to launch missile defense resources against the target. The target will turn a light violet color to indicate that it has been targeted. If you launch an inappropriate missile at an aircraft the plane may not be destroyed and you will have to try again.

AWACS, also known as reconnaissance planes, will also be present on your screen. They are small blue circles labeled A, B, or C. It is their job to determine plane identifications and relay this information to the Intel Officer. The reliability of the AWAC information is dependent upon their location, the closer the plane to home base (center of the grid) the more reliable the information. At 5 to 10 miles out (first two rings), the reliability is 75% at 15 to 20 miles the reliability is 50%, and at 25 to 30 miles the reliability is 25%.

Initially, all aircraft appear as white squares. Below each square is the aircraft target number and its speed. In order for you to determine what type of aircraft is on your radar, you must request this information from the intelligence officer. This is done by typing the aircraft's number in the request box in the middle left side of the radar screen. All you need to do is type in each number followed by the return key. The Intel officer will receive and process your information. It's identity will be shown by the color of the square on your radar screen (ex. blue for friendly fighters). The aircraft number will remain the same, but the penalty points for the identification that has been made will appear below the target number. This may or may not be correct depending on the accuracy of the ID. You must decide what to do with each aircraft, either processing it (destroying it) or letting it land at the base. At all times during this task, your total reward and penalty points are shown at the top left corner of your radar screen.

Once the Intel Officer has sent over his classification for the aircraft, you will receive the AWAC's identification for that particular aircraft. This information will appear in the lower left section of your screen below the requested information box. The plane will be identified by its target number and the AWAC's identification; labeled Source A, Source B, and Source C.

Aircraft will continually appear on your radar screen until the testing time is up. Thus, you could potentially process hundreds of planes in the 6 minutes allotted for each session. Please be aware that this task moves quickly. We want you to work as quickly and as accurately as you can. These instructions may seem a bit confusing, so we will start with several training sessions to help clarify your task.

APPENDIX E : ANOVA Results

AIR COMMANDER

LEVELS ENCOUNTERED DURING PROCESSING ARE:
DISPLAY
1.000 2.000 3.000
WORKLOAD
3.000 6.000 9.000

(Sum of Actual Reward Points)
DEP VAR: **Actual Reward** N: 162 MULTIPLE R: 0.804 SQUARED MULTIPLE R: 0.646

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	1742979.012	2	871489.506	8.680	0.000
WORKLOAD	251666E+08	2	.125833E+08	125.335	0.000
DISPLAY *WORKLOAD	1139891.358	4	284972.840	2.838	0.026
ERROR	.153608E+08	153	100397.095		

(Sum of Actual Penalty Points)
DEP VAR: **Actual Penalty** N: 162 MULTIPLE R: 0.848 SQUARED MULTIPLE R: 0.720

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	376470.370	2	188235.185	5.945	0.003
WORKLOAD	.116314E+08	2	5815696.296	183.682	0.000
DISPLAY *WORKLOAD	431481.481	4	107870.370	3.407	0.011
ERROR	4844255.556	153	31661.801		

(Adjusted Reward Points 0 - 100)
DEP VAR: **Normalized Reward** N: 162 MULTIPLE R: 0.430 SQUARED MULTIPLE R: 0.185

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	87.698	2	243.849	3.170	0.045
WORKLOAD	1822.278	2	911.139	11.844	0.000
DISPLAY *WORKLOAD	359.400	4	89.850	1.168	0.327
ERROR	11770.177	153	76.929		

(Adjusted Penalty Points 0 - 100)
DEP VAR:**Normalized Penalty** N: 162 MULTIPLE R: 0.770 SQUARED MULTIPLE R: 0.593

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	2525.178	2	1262.589	7.359	0.001
WORKLOAD	32809.802	2	16404.901	95.619	0.000
DISPLAY *WORKLOAD	2846.997	4	711.749	4.149	0.003
ERROR	26249.491	153	171.565		

(Categorization time for attacked targets)
DEP VAR: **Categorize to KILL** N: 155 MULTIPLE R: 0.554 SQUARED MULTIPLE R: 0.307

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	82.351	2	41.176	10.108	0.000
WORKLOAD	174.646	2	87.323	21.437	0.000
DISPLAY *WORKLOAD	6.887	4	1.722	0.423	0.792
ERROR	594.720	146	4.073		

(Categorization time for collided targets)
DEP VAR:**Categorize to COLLIDE** N: 102 MULTIPLE R: 0.535 SQUARED MULTIPLE R: 0.286

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	423.445	2	211.723	2.539	0.084
WORKLOAD	2030.438	2	1015.219	12.176	0.000
DISPLAY *WORKLOAD	499.917	4	124.979	1.499	0.209
ERROR	7754.338	93	83.380		

(Categorization time for landed targets)
DEP VAR: **Categorize to LAND** N: 156 MULTIPLE R: 0.891 SQUARED MULTIPLE R: 0.793

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	3437.595	2	1718.798	19.001	0.000
WORKLOAD	46823.232	2	23411.616	258.815	0.000
DISPLAY *WORKLOAD	123.091	4	30.773	0.340	0.850
ERROR	13297.176	147	90.457		

INTELLIGENCE OFFICER

LEVELS ENCOUNTERED DURING PROCESSING ARE:
COVERAGE
1.000 2.000 3.000
POSITION
1.000 2.000 3.000 4.000

DEP VAR: **VIEW TIME** N: 216 MULTIPLE R: 0.344 SQUARED MULTIPLE R: 0.118

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
COVERAGE	14.407	2	7.203	12.824	0.000
POSITION	0.632	3	0.211	0.375	0.771
COVERAGE *POSITION	0.359	6	0.060	0.106	0.996
ERROR	114.585	204	0.562		

DEP VAR:**CORRECT TIME** N: 216 MULTIPLE R: 0.834 SQUARED MULTIPLE R: 0.696

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
COVERAGE	18.889	2	9.444	167.674	0.000
POSITION	3.057	3	1.019	18.091	0.000
COVERAGE *POSITION	4.400	6	0.733	13.020	0.000
ERROR	11.491	204	0.056		

DEP VAR: **VIEWTIME** N: 216 MULTIPLE R: 0.977 SQUARED MULTIPLE R: 0.954

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SUBJECT	93.945	17	5.526	94.178	0.000
COVERAGE	14.407	2	7.203	122.760	0.000
POSITION	0.632	3	0.211	3.590	0.016
COVERAGE *POSITION	0.359	6	0.060	1.018	0.418
SUBJECT *COVERAGE	9.363	34	0.275	4.693	0.000
SUBJECT *POSITION	5.292	51	0.104	1.768	0.008
ERROR	5.985	102	0.059		

DEP VAR:**CORRECT TIME** N: 216 MULTIPLE R: 0.955 SQUARED MULTIPLE R: 0.911

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SUBJECT	4.751	17	0.279	8.501	0.000
COVERAGE	18.889	2	9.444	287.285	0.000
POSITION	3.057	3	1.019	30.997	0.000
COVERAGE *POSITION	4.400	6	0.733	22.308	0.000
SUBJECT *COVERAGE	1.743	34	0.051	1.559	0.046
SUBJECT *POSITION	1.644	51	0.032	0.980	0.522
ERROR	3.353	102	0.033		

LEVELS ENCOUNTERED DURING PROCESSING ARE:
DISPLAY
1.000 2.000 3.000
WORKLOAD
3.000 6.000 9.000

10 CASES DELETED DUE TO MISSING DATA.

(Mean view time)
DEP VAR: **VIEW TIME** N: 152 MULTIPLE R: 0.672 SQUARED MULTIPLE R: 0.451

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	21.120	2	10.560	8.821	0.000
WORKLOAD	108.197	2	54.099	45.190	0.000
DISPLAY *WORKLOAD	15.426	4	3.856	3.221	0.014
ERROR	171.190	143	1.197		

(Mean request time)
DEP VAR:**REQUESTT** N: 78 MULTIPLE R: 0.364 SQUARED MULTIPLE R: 0.132

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	158.485	2	79.243	2.822	0.066
WORKLOAD	62.682	2	31.341	1.116	0.333
DISPLAY *WORKLOAD	44.148	4	11.037	0.393	0.813
ERROR	1937.224	69	28.076		

(Percent requested transformed)
DEP VAR:**AREQUEST** N: 158 MULTIPLE R: 0.567 SQUARED MULTIPLE R: 0.321

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	7.896	2	3.948	20.660	0.000
WORKLOAD	5.546	2	2.773	14.511	0.000
DISPLAY *WORKLOAD	0.838	4	0.209	1.096	0.361
ERROR	28.474	149	0.191		

(Percent on top list transformed)
DEP VAR: **ATOP** N: 158 MULTIPLE R: 0.544 SQUARED MULTIPLE R: 0.296

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
DISPLAY	2.134	2	1.067	10.832	0.000
WORKLOAD	3.454	2	1.727	17.529	0.000
DISPLAY *WORKLOAD	1.054	4	0.263	2.674	0.034
ERROR	14.678	149	0.099		

GLOSSARY

AMRAAM	Advanced Medium Range Air to Air Missile
ANOVA	Analysis of Variance
AWACS	Airborne Warning and Control System
SA	Situation Awareness